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Research Report

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Barriers to the Commercialization and Adoption of New Underground Coal Mining Technologies in the United States

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About This Report

This report presents results of a project characterizing barriers to the development, commercialization, and adoption of new technologies for use in underground coal mining in the United States. The findings are based on structured interviews and a workshop with representatives of organizations involved in different aspects of the U.S. underground coal mining technology market (i.e., manufacturer, supplier, user).

This research was sponsored by the Mining Program of the National Institute for Occupational Safety and Health (NIOSH). The findings are intended to help the NIOSH Mining Program achieve its goal, as stated in the Mine Improvement and New Emergency Response (MINER) Act of 2006, of enhancing and expediting the development and commercial availability of new mine safety technology and technological applications. The findings are also expected to support the U.S. Mine Safety and Health Administration's ongoing efforts to update mine safety and health regulations.

Community Health and Environmental Policy Program

RAND Social and Economic Well-Being is a division of the RAND Corporation that seeks to actively improve the health and social and economic well-being of populations and communities throughout the world. This research was conducted in the Community Health and Environmental Policy Program within RAND Social and Economic Well-Being. The program focuses on such topics as infrastructure, science and technology, community design, community health promotion, migration and population dynamics, transportation, energy, and climate and the environment, as well as other policy concerns that are influenced by the natural and built environment, technology, and community organizations and institutions that affect well-being. For more information, email chep@rand.org.

Acknowledgments

We are indebted to the interview and workshop participants for their time and willingness to share their insights about underground coal mining technology development and commercialization. We also gratefully acknowledge our formal peer reviewers, David Metz at RAND and James Dean at West Virginia University, for their comments and suggestions, which greatly improved the presentation of this material.

Summary

Although the U.S. coal mining market has been contracting in recent years as demand for coal has slackened, it remains substantial. The industry produced 577 million short tons of coal in 2021, 38 percent of which (221 million short tons) was produced in underground coal mines by 24,000 workers in 15 states. Underground coal mining is a highly specialized industry. The combination of the harsh environment, heavy equipment, physical hazards, and potentially toxic and combustible atmospheres creates a challenging operating environment and hazardous working conditions. Because of the inherent challenges in developing reliable and safe mining technology, as well as the historical economic importance of the mining sector, the federal government has long provided both support and oversight for technology development and use in mining.

Three multiple-fatality coal mining accidents in 2006 led Congress to pass the Mine Improvement and New Emergency Response Act (MINER Act) of 2006 (Pub. L. 109-236, 2006). Among other topics, the MINER Act addresses research and development of safety technology for underground coal mining. An important element of the act was the establishment the Office of Mine Safety and Health Research within the National Institute for Occupational Safety and Health (NIOSH) to expedite the development and commercial availability of new safety technologies for underground coal mining. Although the NIOSH Mining Program has facilitated the development of several new technologies to improve underground coal mining safety and health, it has observed that the commercialization and widespread adoption of technologies face formidable barriers.

To improve its ability to carry out its charge under the MINER Act, NIOSH desires to better understand these barriers and explore their implications for NIOSH research. The objective of this study was to characterize the barriers to commercial availability and implementation of safety and health protection technology in U.S. underground coal mines. A RAND Corporation team undertook this task by (1) conducting a series of structured interviews with representatives of a sample of organizations that have a stake in the U.S. underground coal mining market and (2) holding a workshop with selected stakeholders to refine and prioritize the barriers and to identify solutions to them.

We conducted 75 interviews with representatives of 54 organizations that spanned a range of types directly or indirectly involved in the underground coal mining technology market, including engineering, design, construction, and consulting firms; labor organizations; legal firms; mining companies; professional organizations; regulatory agencies; research and development organizations; standards development organizations; suppliers of major equipment; and suppliers of other technology.

Through these interviews, we identified and characterized 24 barriers. To help understand the origins of barriers and potential options for addressing them, we distinguished three groups of barriers (economic, regulatory, and other) and several subgroups within each group. The majority of identified barriers (15, or 62 percent) are associated with regulatory issues and fall into six subgroups reflecting

different aspects of the regulatory process to approve technology for use in underground coal mines: the cost of approval, the duration of the approval process, the currency of regulations, the prescriptiveness of standards, mine operator burden, and regulatory culture. Most of the other barriers (six, or 25 percent) are associated with economic factors: insufficient demand, insufficient supply, and the specialized market for underground coal mining. The remaining three barriers, grouped as "other," are associated with mine operator culture, liability, and federal support.

The individual barriers span a variety of specific issues, and in several cases interview participants provided examples illustrating implications. Most barriers have the effect of dissuading suppliers from developing new technologies, updating existing technologies, or even entering or remaining in the underground coal mining market at all.

The most commonly cited barrier was cited in 29 of the 75 interviews, while two barriers were cited just once each. The five most commonly cited barriers, the number of times they were cited, and their barrier category are as follows:

- Barrier 8: Duration of technology approval dissuades developers (29) (regulatory).
- Barrier 1: Small U.S. market makes it difficult for suppliers to recoup investments in new technology (26) (economic).
- Barrier 2: Shrinking market leads to incumbent dominance (23) (economic).
- Barrier 15: MSHA-specific standards isolate U.S. underground coal mining market (21) (regulatory).[1]
- Barrier 7: Cost of technology approval dissuades developers (19) (regulatory).

The workshop used a Delphi approach to prioritize the barriers in terms of their frequency of occurrence and their magnitude. Eight barriers emerged as highest priority in terms of both metrics:

- Barrier 8: Duration of technology approval dissuades developers (regulatory).
- Barrier 17: Approval of technology is often required for small design or part changes (regulatory).
- Barrier 1: Small U.S. market makes it difficult for suppliers to recoup investments in new technology (economic).
- Barrier 7: Cost of technology approval dissuades developers (regulatory).
- Barrier 15: MSHA-specific standards isolate U.S. underground coal mining market (regulatory).
- Barrier 9: Technology approval applications are canceled when more than minor discrepancies are found (regulatory).
- Barrier 21: Conservative and risk-averse culture (regulatory).
- Barrier 12: MSHA standards are out-of-date (regulatory)

The large overlap between the barriers most commonly cited in the interviews and the barriers deemed highest priority in the workshop (the high-priority barriers include four of the five most commonly cited barriers) lends support to the high priority of this subset of barriers.

[1] MSHA stands for the Mine Safety and Health Administration.

Seven of the eight high-priority barriers fall into the regulatory group. Regulatory barriers make up more than half of all barriers identified, and the further concentration of regulatory barriers in the high-priority set demonstrates the priority of regulatory barriers relative to others.

Solutions proposed in the workshop centered on streamlining the MSHA approval process, modernizing MSHA standards, increasing stakeholder interaction in efforts to update mining technology and the associated regulatory regime, and increasing federal support for mining technology.

The findings have implications for NIOSH. For example, one barrier is that mine operators are reluctant to exceed regulatory requirements for safety technology. In light of this behavior, NIOSH may want to consider all potential regulatory requirements when investing in new technology research, pursuing technologies that are most likely to help operators meet regulatory requirements. In terms of ways in which NIOSH may facilitate the elimination of barriers, NIOSH research on the equivalency between MSHA and International Electrotechnical Commission standards has already proven essential to MSHA's willingness to consider granting technology approval according to voluntary consensus standards in lieu of MSHA standards. The majority of barriers, however, relate to issues that are beyond NIOSH's direct influence, and NIOSH is likely to play a secondary role in addressing them.

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Chapter 1

Introduction

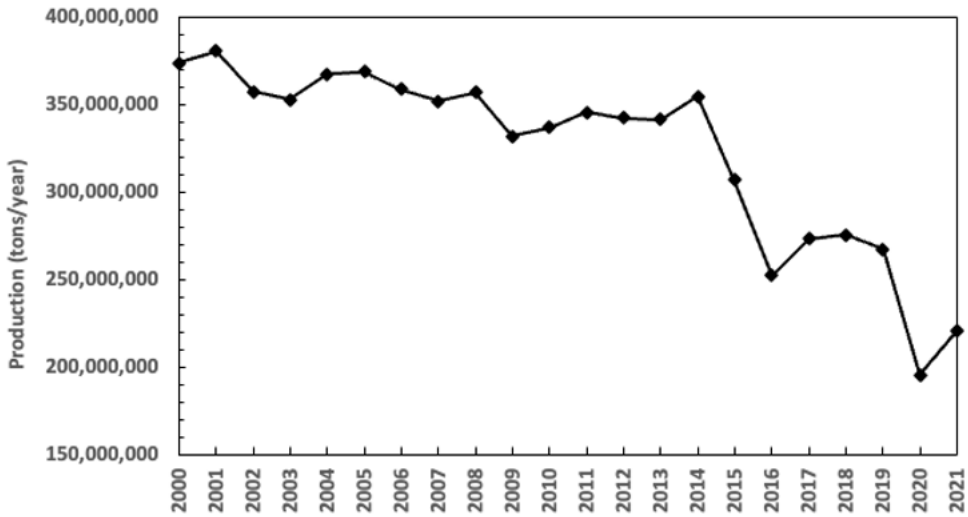
Underground Coal Mining in the United States

The underground coal mining industry in the United States in 2021 employed approximately 24,000 workers in 174 mines in 15 states and produced approximately 221 million tons of coal, primarily for electric power generation (U.S. Energy Information Administration [EIA], 2022). This underground production represented 38 percent of the total coal produced in the United States, with the remaining 62 percent coming from surface mines. About 58 percent of underground production was from mines that use primarily longwall mining operations, 42 percent was from mines that use primarily continuous mining operations, and less than 1 percent was from mines that use conventional or other mining methods (EIA, 2022).

These statistics are in flux, as coal production in the United States, including both surface and underground, has been declining for several years. Historical trends for underground coal mining production, number of mines, and employment are shown in Figures 1.1, 1.2, and 1.3, respectively. The reason for the increase in employment from 2003 to 2012, despite decreases in production and the number of mines during this period, is unknown. In addition to the large reduction in employment from 2012 to 2016 and the general trend of lower production, the contraction of the market has reduced the number of companies through mergers and bankruptcies, among both mine operators (e.g., the merger of Contura Energy and Alpha Natural Resources in 2018 and the bankruptcy of Murray Energy, formerly the largest producing underground coal mining company in the United States, in 2019) and technology suppliers (e.g., the merger of Joy Global and Komatsu Limited in 2017).

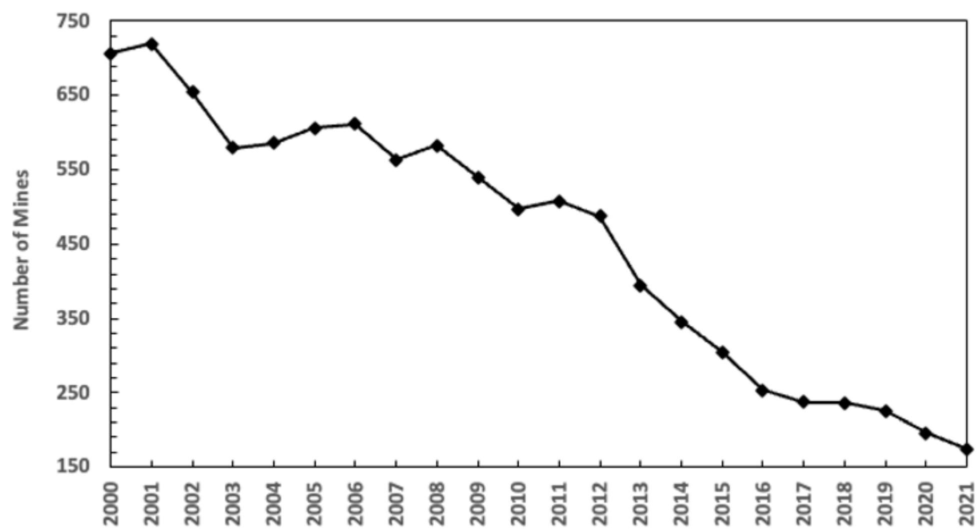
Worldwide coal production in 2020 was 7.6 billion tonnes (8.4 billion short tons) (International Energy Agency, 2021). China was the leading producer by far, accounting for 50 percent of the total. India was the second largest producer, with 12 percent of the total, and the United States was fifth, with 6 percent. Relative proportions of underground and surface coal production are not available for global coal production, although the World Coal Association notes that "underground mining currently accounts for a bigger share of world coal production than opencast" (World Coal Association, undated).

Figure 1.1. U.S. Underground Coal Mining Production over Time



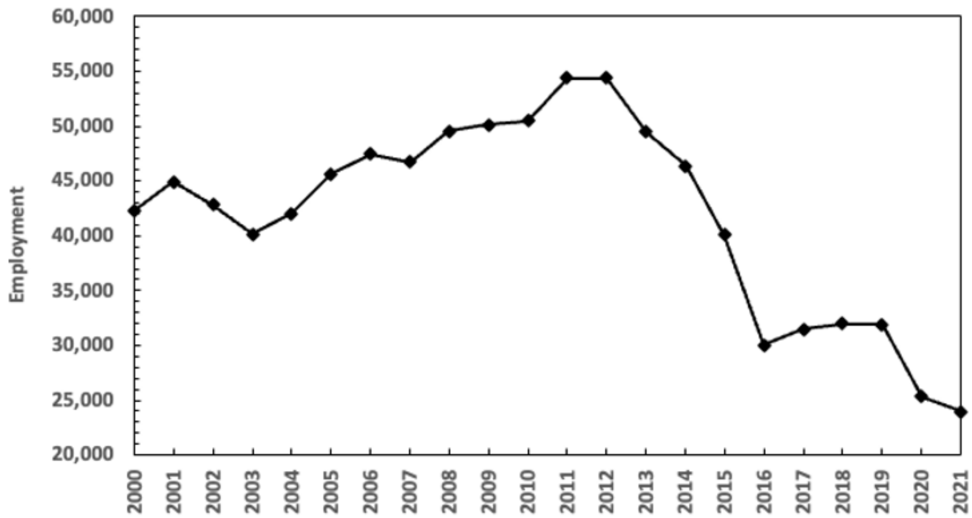
SOURCE: Data from EIA annual reports for 2001–2022 (see EIA, 2023).

Figure 1.2. Number of U.S. Underground Coal Mines over Time



SOURCE: Data from EIA annual reports for 2001–2022 (see EIA, 2023).

Figure 1.3. U.S. Underground Coal Mining Employment over Time



SOURCE: Data from EIA annual reports for 2001–2022 (see EIA, 2023).

Underground coal mining production in the United States is dominated by a few large companies, with several smaller companies contributing the remainder. In 2014, five companies (Murray Energy Corporation, Alliance Resource Partners, Alpha Natural Resources, Consol Energy, and Foresight Energy) accounted for 54 percent of the market share for underground coal.[2] It should be noted these companies were not necessarily the top overall coal producers, as production from larger companies, such as Peabody Energy and Arch Resources, Inc., comes primarily from surface mining. The market is dynamic, however, and as it contracts, companies have merged and reorganized. Since 2014, Murray Energy Corporation acquired Foresight Energy, went bankrupt, and reemerged as American Consolidated Natural Resources, Inc. Similarly, Alpha Natural Resources and Contura Energy merged and have become Alpha Metallurgical Resources.

Factors Shaping the Underground Coal Mining Technology Market

Technology used in underground coal mining must be able to withstand the harsh physical conditions present in the mining environment. In addition, because of the special safety risks associated with underground coal mines—such as the presence of toxic and combustible gases and dust, which can lead to lung damage, explosions, and other hazards—equipment must be specially designed to minimize risks to workers. Because of the inherent challenges in developing reliable and safe mining technology, as well as the historical economic importance of the mining sector, the federal

[2] We took production data taken from company websites, Form 10-K filings for the U.S. Securities and Exchange Commission, and EIA annual coal reports (EIA, 2023).

government has long provided both support and oversight for technology development and use in mining.

In December 1907, President Theodore Roosevelt called for the creation of a bureau of mines that would "have power to collect statistics and make investigations in all matters pertaining to mining and particularly to the accidents and dangers of the industry" (Roosevelt, 1907). That year was (and still is) the most lethal in U.S. history for underground coal mining disasters, with more than 900 workers killed (National Institute for Occupational Safety and Health [NIOSH], undated-a). Congress established the U.S. Bureau of Mines in 1910 (NIOSH, 2012). The principal activity of the Bureau of Mines was to help develop technologies and practices that would ensure the availability of mineral resources and could be used safely in the presence of flammable gases and dust.

Mining safety in the United States improved significantly over several decades. However, in 1968, after nearly 20 years of relatively few mining fatalities, 108 workers died in mining disasters, including 78 in a single disaster (NIOSH, undated-a). In response, the federal government's oversight role was strengthened with the Federal Coal Mine Health and Safety Act of 1969 (Pub. L. 91-173, 1969). This act established a suite of mandatory safety standards and mine inspection requirements, which included technology standards and approval authority. This government regulatory function, initially housed in the Bureau of Mines, was expanded and transferred initially in 1973 to the Mining Enforcement and Safety Administration under the Department of the Interior and then to the Mine Safety and Health Administration (MSHA) under the Department of Labor in 1977 as part of the Federal Mine Safety and Health Amendments Act (Pub. L. 95-164, 1977).

The Bureau of Mines was dissolved in 1996, and its principal functions were transferred to other federal agencies. The health and safety research work was transferred briefly to the U.S. Department of Energy and then to NIOSH, while other functions were transferred to the Department of Energy, the U.S. Geological Survey, and the Bureau of Land Management. Notably, production technology development, the primary function for which the Bureau of Mines was created, was not transferred to NIOSH, and as a result NIOSH generally does not do any production technology research for mining unless it can be tied to safety.

Underground coal mining fatalities and fatality rates have continued to decline steadily over time (NIOSH, undated-b). However, after 25 years of one or no underground coal mining disasters per year, three multiple-fatality mining accidents in 2006 at the Sago, Aracoma, and Darby mines (Kowalski-Trakofler et al., 2009) led Congress to pass the Mine Improvement and New Emergency Response Act (MINER Act) of 2006 (Pub. L. 109-236, 2006). The MINER Act amended the Federal Mine Safety and Health Amendments Act and the Occupational Safety and Health Act of 1970 (Pub. L. 91-596, 1970) to improve the safety of mines and mining. The MINER Act addresses safety and health topics related to underground mining, particularly in the areas of emergency preparedness, rescue, accident investigations, and safety technology research and development.

Much progress has been attributed to the MINER Act. For example, the assistant secretary for mine safety and health noted in 2011,

> We are finally seeing the installation of wireless or nearly wireless two-way communications and electronic tracking systems, as mandated by the MINER Act. I have no doubt that these impressive technologies would not have been developed for

> coal mines by the private sector had the MINER Act not adopted its aggressive technology-forcing provisions five years ago. (Main, 2012)

An important element of the MINER Act was the establishment the Office of Mine Safety and Health Research within NIOSH.[3] This office, now referred to as the NIOSH Mining Program, was created "to enhance the development of new mine safety technology and technological applications and to expedite the commercial availability and implementation of such technology in mining environments" (Pub. L. 109-236, 2006). The NIOSH Mining Program manages a $45 million portfolio of intramural and extramural research addressing key concerns related to safety technology and practices. Research priorities are identified based on assessments of burden, need, impact, stakeholder input, and the regulatory agenda, including rulemaking by MSHA (NIOSH, 2021). In addition, the NIOSH Mining Program engages in partnerships with its stakeholders to share information and solutions about some of the most-pressing health and safety issues.

Although the NIOSH Mining Program has facilitated the development of several new technologies to improve underground coal mining safety and health (NIOSH, 2023), it has observed that the commercialization and widespread adoption of technologies face formidable barriers. First, some parts of the market are very specialized in terms of their specific technical needs, so many of the technologies must be purpose-built for underground coal mining. In addition, the working environment is hazardous and physically harsh, which puts extra constraints on the design and performance of technologies to ensure that they can operate safely and reliably. Although safety concerns warrant careful regulatory oversight, there are indications that the current regulatory environment presents barriers to technology commercialization. The National Occupational Research Agenda, Mining Sector Council (2015), has noted in its national mining agenda that the current regulatory environment would benefit from impartial review and research on alternative codes of practice and systems of regulation, as well as continued research to promote innovation in technologies to improve the health and safety of mining personnel. Finally, as demand for coal decreases and the market contracts, opportunities for innovation, investment, and new entrants are limited.

Purpose and Task of Study

The barriers to technology commercialization and adoption impede the NIOSH Mining Program's ability to carry out its charge under the MINER Act of expediting the commercial availability and implementation of new mine safety technology. As a federal research agency, NIOSH has limited visibility into the technology market. Even though the Mining Program partners with industry to help develop technologies and share information, the commercialization and adoption of technologies are ultimately up to technology suppliers and technology users (coal mine operators). To improve the efficacy of the contract and grant awards that it administers under the authority of the MINER Act, NIOSH needs a more complete understanding of the barriers to technology

[3] NIOSH was established under the Occupational Safety and Health Act of 1970. The organization is part of the U.S. Centers for Disease Control and Prevention in the U.S. Department of Health and Human Services. The mission of the NIOSH Office of Mine Safety and Health Research, now referred to as the NIOSH Mining Program, is "to eliminate mining fatalities, injuries, and illnesses through relevant research and impactful solutions" (U.S. Centers for Disease Control and Prevention, 2017).

commercialization and adoption from the point of view of the mine operators and technology innovators.

To this end, NIOSH asked RAND Corporation researchers to characterize the barriers to commercial availability and implementation of safety and health protection technology in U.S. underground coal mines from the perspective of the organizations that purchase, use, approve, and manufacture these safety technologies. We undertook this task by conducting a series of structured interviews and a workshop with representatives of a sample of organizations with a stake in the U.S. underground coal mining market (stakeholder representatives). The interviews were conducted to elicit and characterize barriers, while the workshop was intended to prioritize barriers and identify options for eliminating them.

The findings of this work are intended to help the NIOSH Mining Program in two ways:

1. *Help make the best use of the funds entrusted to NIOSH in its contracts and grants program to expedite the availability and implementation of technologies.* There are many technologies that NIOSH could fund, but the money to do so is quite limited, and NIOSH desires to focus on those that provide the most benefit with some realistic possibility of being adopted by the mining industry. To assess the likelihood of adoption, a thorough understanding of the implementation barriers is essential.
2. *Identify those barriers that NIOSH may be able to help alleviate in its role as a research organization.* The findings will help provide an understanding of which issues are appropriate for NIOSH to try to influence. This is important because some of the suspected issues could require NIOSH to enter into research areas that require the addition of new expertise and substantial commitment of resources. Such changes require a compelling justification given the finite pool of resources and the competing budget priorities.

Chapter 2

Study Methods

Study Scope and Participant Population

Identifying appropriate interview participants is important for ensuring that relevant knowledge about and experience with different technologies are considered in our exploration of barriers to commercialization and adoption. The population sampled for the interviews is representative of organizations that participate in, either directly or indirectly, the U.S. market for underground coal mining technology. Such stakeholder organizations include those that purchase, use, approve, and manufacture technology, as well as those that advise about or litigate issues related to technology use.

To help identify organizations, we first defined different categories of stakeholders:

- *engineering, design, construction, and consulting:* companies that design, engineer, or construct underground coal mines, or individuals and companies that supply one or more of these services on a consulting or contract basis
- *labor:* organizations that represent underground coal miners on labor issues
- *legal:* firms or individuals that represent companies in litigation and in filing petitions, appeals, and other legal activities
- *mining:* companies that own or operate underground coal mines
- *professional:* organizations that have an interest in the advancement, safety, and regulation of underground mining
- *regulatory:* state and federal government organizations that develop and enforce underground mining regulations
- *research and development:* government laboratories, universities, companies, and other entities involved in the research and development of technologies to improve mining operation efficiencies and the safety and health of underground coal miners
- *standards development:* nongovernmental organizations that develop voluntary consensus standards for technology and procedures
- *technology (major equipment):* suppliers of complete pieces of equipment used for underground coal mining operations (continuous mining machines, longwall shearers, bolters) or transportation (shuttle cars, personnel carriers)
- *technology (other):* suppliers of technology (other than major equipment) used in underground coal mining.

This variety of types of organizations is intended to ensure that interview participants had a diversity of perspectives and experiences related to underground coal mining technology.

When considering technology suppliers, we endeavored to cover a broad range of technologies used in underground coal mining that go beyond those strictly focused on worker safety. We took this approach because there are safety aspects associated with all technologies used in underground coal mining and because many safety technologies must integrate or interface with other mining equipment (e.g., proximity detection). In light of the high fire and explosion hazard in underground coal mines and the associated regulatory requirements for electrically powered equipment used in them, our analysis focused primarily on electrical and electronic technologies. Technologies addressed in our analysis include the following:

- air quality control, including powered respirators, ventilation systems, and emission controls
- air quality monitoring, including gas sensors and dust monitors
- communications and tracking, including personnel and asset tracking, proximity sensing, and audio and video communications
- efficiency optimization, such as remote control and automation
- emergency response, including refuge chambers, backup air supplies, and fire suppression systems
- mining operation, such as continuous mining machines, longwall shearers, bolters, and shuttle cars.

Primarily mechanical or pneumatic technologies and materials—such as hearing protection, brattices and stoppings, rock dusting, and materials used for ground control, conveyer belts, and cutting materials—were not specifically pursued.

An important consideration in our search was to gain perspective on the issues associated with underground coal mining in the United States compared with those for underground coal mining in other countries and on issues with underground coal mining compared with those for other industries. To this end, we included organizations that operate both in the United States and in other countries and organizations that operate both in underground coal mining and in other industries.

To identify stakeholder organizations, we drew on searches of technology supplier and mining company websites, mining publications, trade association websites and member directories, federal and state regulator websites, university mining research programs, and other sources. We also drew on MSHA's list of approved products (MSHA, undated-a) to identify technology suppliers. Our search was augmented with input from the NIOSH Mining Program staff. In addition, we reviewed 130 stakeholder comments about regulatory reform submitted to MSHA from 2017 to 2019 in response to its call for input as required by Executive Order (EO) 13777 (2017), "Enforcing the Regulatory Reform Agenda." From these comments, we identified candidates that had expressed concerns about market barriers stemming from regulatory issues.

Because the visibility and relevance of organizations is inconsistent, we did not attempt to compile a comprehensive list of stakeholder organizations. We did, however, attempt to identify large, influential, or innovative organizations in each of the stakeholder categories. Our search was global, but we restricted our sample to those organizations that conduct operations within the United States.

Our sampling approach was to include essentially as many representatives from each category as we could enlist to participate. We also used a snowball sampling approach, in which we asked interview participants for suggestions for additional individuals or organizations to include.

Interview Protocol

To maintain internal consistency and facilitate comparisons among interview participants, we developed structured interview protocols. The most important stakeholder categories were technology (major equipment), technology (other), and mining (which together were two-thirds of the interviews), so we developed the main interview protocol targeting representatives of organizations in these categories. For most other stakeholder categories, we used the same protocol but skipped questions that did not apply. One exception was the regulatory category, for which we developed a separate protocol. Interview protocols are presented in Appendix A.

The overall goal of the interviews was to characterize barriers to the commercialization and adoption of new technologies for use in underground coal mining. The main interview protocol began with some general questions about the technology development process and technology awareness and selection. The protocol then raised the question of what the main barriers to technology commercialization and adoption are and what possible solutions to eliminating them might exist. When asking about barriers, we prompted interview participants to consider barriers stemming from economic, cultural, technical, regulatory, or other issues. However, we never provided examples or other types of prompts for anything more specific than these broad categories. The interviews ended with some questions probing for specific examples of consequences of these barriers, including technologies available in other countries or other industries but not in underground coal mining in the United States, technologies that were developed but never commercialized, and technologies without a similar alternative that have been discontinued.

The regulatory protocol was developed during the course of the interviews and was based in part on findings from interviews with representatives of technology suppliers. Technology suppliers and mine operators often cited aspects of the regulatory regime and process as significant barriers, which led to several questions for interviews with regulators. As a result, we deferred interviews with regulators until we had developed a suite of questions for them. Our interviews with representatives from the regulatory category were intended to focus less on identifying barriers than on providing balance, context, and verification for the regulatory-related barriers raised in our interviews with industry representatives. Some of the questions focused on the technology approval process, while others raised more-general questions about the use of non-MSHA standards and the standards development process.

Interview candidates were contacted by email. All invitations that went unanswered were followed up with at least two reminder emails. In most cases, invitations were sent to individual representatives who had been identified ahead of time. In other cases, the invitations were sent to the organization's general-information email address. The invitation described the objectives of the project and requested a one-hour interview. The invitation also clearly stated that all interviews for this project were being conducted on a not-for-attribution basis, meaning that neither individuals' nor organizations' names would be revealed to anyone outside RAND, including NIOSH. All reports to NIOSH and the public attribute findings only to the level of stakeholder category. We chose to present the findings anonymously because we anticipated that barriers to commercialization may involve regulatory issues and recognized the potential sensitivities involved in asking technology suppliers and others to discuss their concerns about the regulatory process in a public setting in which they may fear retaliation from regulators. The message also noted that this study was not associated with any specific regulatory analysis or decision.

Interviews were conducted by telephone (no video) between January and November 2020. Each interview included a single interview participant and two members of the RAND team. In some cases, multiple individuals from the same organization were interviewed (separately). This usually occurred for larger organizations in which different people had different areas of expertise and experience and the representatives thought that it was important for us to meet with more than one person. Both RAND participants took notes during the interviews. In addition, interviews were recorded to provide an accurate transcript. Transcripts were not shared with anyone outside RAND, including NIOSH.

Interview Data Analysis

Although the interview protocol included a variety of questions (Appendix A), the primary target of the analysis was to identify and characterize barriers to the commercialization and adoption of technologies. Questions 6–11 bear directly on this goal and consequently were the main focus of both the interviews and the analysis. Questions 1–5 helped to set the stage and explore the technology development process but typically shed little light on the question of barriers.

Results of the stakeholder interviews were analyzed using an adaptive content analysis approach, sometimes referred to as *recursive abstraction* (Polkinghorne and Arnold, 2014; Oun and Bach, 2014; Polkinghorne and Taylor, 2019). This method is characterized by repeated summarization of the data into distinct themes, with the objective of reducing the number of themes and achieving increasingly higher levels of abstraction in each cycle. Our analytical objective was to identify and characterize individual barriers that are distinct from each other in terms of their origins or implications. Because interviews with representatives of the regulatory stakeholder category did not focus on identifying barriers, they were excluded from the analysis. In keeping with the recursive abstraction approach, we endeavored to merge and minimize the number of barriers whenever a clear case for distinction was lacking. However, although this approach did result in defining some barriers that represent composites of multiple descriptions of slightly different issues, the amount of interpretation and abstraction required to characterize them was minimal. This helped us avoid one of the shortcomings of recursive abstraction, which is that final abstracted themes can become disconnected from the raw data, and questions about reliability and reproducibility may arise. In effect, our analysis differed little from more-conventional coding-based content analysis in which our abstracted themes (i.e., barrier groupings and individual barriers) are analogous to codes, with the exception that they were allowed to be refined and merged as data were added.

We used the same approach to sort and group the barriers according to higher-level themes. These higher-level themes help to concisely convey more-general sources of barriers, which will be useful when developing options for eliminating barriers and for understanding the roles of different actors in implementing the options.

When describing a barrier, interview participants often provided examples of instances in which that barrier was encountered. In addition, the interview protocol included questions specifically intended to elicit examples of challenges with technology availability that may result from barriers

(Appendix A). We have included these examples in our presentation of results to help illustrate the kinds of challenges market stakeholders face.

A challenge with qualitative interviews is verifying the accuracy of the data. Most of the input from the interviews consists of personal experiences and opinions, for which verification is generally not possible. But when interview participants described more-factual information, we did attempt to verify it. In many cases, interview participants cited specifics of the regulatory process in their descriptions of barriers. Hence, an important source for verification was regulatory documents and interviews with representatives of regulatory agencies (primarily MSHA). These interviews served to provide context and clarification for statements about regulatory procedures and practices made by industry representatives.

Workshop

After the interviews were completed, we convened a workshop that was intended to accomplish the following:

1. Clarify and define the barriers identified in the interviews, as needed.
2. Prioritize barriers in terms of their merit for attention.
3. Develop and prioritize options for eliminating barriers.

The workshop participants consisted of a subset of interview participants. Workshop invitees were selected based on the extent of knowledge and insights conveyed in the interviews. We also attempted to include representation across the stakeholder categories among the invitees. The target size for the workshop was ten to 15 participants. Thirty-one people were invited to participate, ten accepted the invitation, and eight ultimately participated in the workshop. Because of the COVID-19 pandemic, the workshop was held virtually. Participants were on camera, and we used screen sharing to present materials. As with the interviews, the workshop was conducted on a not-for-attribution basis.

The primary input to the workshop was the results of the stakeholder interviews. We began the workshop with a presentation that covered the objectives of the overall study, the methods used, and the barriers that were identified in the interviews and how we classified and organized them. The remainder of the workshop was divided into three sessions, each addressing one of the workshop objectives. The workshop agenda is provided in Appendix B.

Session 1: Refine Barrier Taxonomy

The first session was reserved for reviewing the interview results and barriers to technology commercialization. This session was used to familiarize the participants with the identified barriers and to provide the opportunity to confirm or refine the barrier definitions and groupings. The intention was to arrive at a set of independent barriers that fully cover the range of issues raised in the interviews. This session consisted of an unstructured discussion and was scheduled to last one hour.

Session 2: Prioritize Barriers

The goal of the second session of the workshop was to prioritize the individual barriers in terms of the extent to which they merit attention and resources. The session used the Delphi method, an approach for eliciting a consensus view from a group of experts (Dalkey, 1969). In this method, participants respond to questions, the responses are combined and presented back to the group, the results are discussed, and then the participants respond to the questions again. The discussion focuses on the rationale for and against outlier responses, with the intention of persuading participants to revise their responses in the subsequent round, moving the group closer to consensus. This process is repeated a predetermined number of times or until a consensus is reached.

Barrier priority was considered in terms of two components: how frequently a given barrier arises and the magnitude of the barrier. Scoring options were qualitative and relative. For frequency, the question read, "Please provide your assessment of the relative frequency with which each of the barriers listed below comes into play across the U.S. underground coal mining market overall (4 = most frequent; 3 = more often than most others; 2 = less often than most others; 1 = least frequent)." The question for magnitude similarly read, "Please provide your assessment of the relative magnitude with which each of the barriers listed below comes into play across the U.S. underground coal mining market overall (4 = greatest magnitude; 3 = greater than most others; 2 = less than most others; 1 = least magnitude)."

Working individually, participants scored each barrier according to frequency of occurrence; responses were submitted anonymously, and results were then presented back to the group in the form of a histogram showing the distribution of scores for each barrier. When reviewing the results, the workshop moderator drew attention to barriers for which scores showed no clear clustering and asked for volunteers to describe their rationale for assigning high and low scores. After the discussion, participants conducted a second round of scoring, and the resulting histogram was again presented to the group. No further rounds of discussion and reranking were conducted. The same scoring process was then conducted for barrier magnitude.

This session was scheduled to run for 1.5 hours.

Session 3: Solutions

The third session of the workshop focused on identifying opportunities to eliminate, reduce, or work around barriers. The session began with RAND representatives summarizing some preliminary options that emerged from the stakeholder interviews. Participants were asked to expand on and add to these options. In addition, participants were instructed to characterize each option in terms of the principal actor, which barriers the option addresses, and feasibility. This session consisted of an unstructured discussion and was scheduled to last one hour.

Chapter 3

Results

Interview Response Rate and Distribution

We sent invitations to 180 interview candidates and conducted 75 interviews. This translates to an overall response rate of 42 percent, which aligns with expectations based on experience with similar types of stakeholder interview projects we have conducted in the past. Of those that were not interviewed, half declined to participate and half did not respond (Table 3.1). Invitees who declined to participate generally provided no explanation for their decision. Although interviews were conducted during the COVID-19 pandemic, interview candidates did not cite the pandemic as a reason for not participating. Most interviews took about an hour to complete.

Table 3.1. Individual Interview Responses

Response Type	Number	Percentage
Accepted and interviewed	75	42
Declined to participate	52	29
No response or invalid contact	53	29
Total	180	100

Responses are presented by stakeholder category in Table 3.2. The 75 interviews were conducted among 54 organizations. The distribution of interviews among categories is generally similar to the distribution of candidates among categories, with the exception of the research and development and legal categories. These categories are underrepresented in our sample compared with the other categories. This undersampling was deliberate, supported by the finding that most stakeholders in these categories offered relatively little insight into the questions we were pursuing. The interviews were dominated by the technology (other), technology (major equipment), and mining categories, which together accounted for 65 percent of both interviews and organizations. Because of the contraction of the coal market in recent years, the number of companies operating underground coal mines has decreased substantially, leaving fewer active mine operators in the market. The number of suppliers of major underground coal mining equipment has also declined through mergers and market exits, leaving a very small pool of active companies.

Table 3.2. Interviewee Organizational Demographics

Organization Type	Number of Interviews	Percentage	Number of Organizations	Percentage
Engineering, design, construction, and consulting	5	7	5	9
Labor	1	1	1	2
Legal	3	4	2	4
Mining company	13	17	9	17
Professional association	1	1	1	2
Regulatory	10	13	3	6
Research and development	4	5	4	7
Standards development organization	2	3	2	4
Technology supplier (major equipment)	10	13	3	6
Technology supplier (other)	26	35	24	44
Total	75	100	54	100

NOTE: Percentages do not sum to 100 because of rounding.

We did not specifically keep track of which companies conduct business outside the United States or outside the underground coal mining market, but many if not most of the technology suppliers do one or both. In fact, several of the companies we met with that had their roots in underground coal mining told us that, as the coal market contracts, they are increasingly expanding to other markets, sometimes maintaining a presence in coal only to serve existing customers that depend on them.

Barriers to Technology Commercialization and Adoption

Interview participants were generally prepared with thoughts on barriers to technology commercialization and adoption and were forthcoming in describing them. In many cases, interviewees provided examples that illustrated the challenges or implications of particular barriers. Many confirmed the sensitivities in discussing this subject and appreciated the fact that interviews were being conducted on a not-for-attribution basis. As described in the methods section, we provided no examples or prompts for barriers while conducting the interviews; all barriers were introduced by interview participants.

Our analysis identified 24 barriers (Table 3.3). To aid in navigating the origins of barriers and potential options for addressing them, we divided the barriers into groups and subgroups. The order in which barriers, barrier groups, and barrier subgroups are listed is not significant. Most barriers fall in the regulatory group. Table 3.3 also shows the number of interviews in which a particular barrier was mentioned. The relative frequency with which a barrier was mentioned provides a measure of the pervasiveness of awareness and impact of that barrier among market stakeholders.

Table 3.3. Barrier Taxonomy

Barrier Group	Barrier Subgroup	Barrier	Number of Interviews	Citation Ranking
Economic	Insufficient demand	1. Small U.S. market makes it difficult for suppliers to recoup investments in new technology	26	2
		2. Shrinking market leads to incumbent dominance	23	3
		3. Mine operators lack funds to invest in new technology	14	8
		4. Unwillingness to exceed regulatory requirements for safety technology	11	11
	Insufficient supply	5. Technology developers lack resources to commercialize	4	17
	Specialized market	6. Harsh physical environment in mines dissuades potential developers	4	17
Regulatory	MSHA approval cost	7. Cost of technology approval dissuades developers	19	5
	MSHA approval duration	8. Duration of technology approval dissuades developers	29	1
		9. Technology approval applications are canceled when more than minor discrepancies are found	5	14
		10. Lack of transparency about technology approval application status	5	14
		11. Poor coordination between MSHA and NIOSH	2	21
	Currency of MSHA regulations	12. MSHA standards are out-of-date	16	7
		13. MSHA regulatory environment is unequipped to address new technology	3	20
	Prescriptiveness of MSHA standards	14. Prescriptiveness crowds out novel approaches	18	6
		15. MSHA-specific standards isolate U.S. underground coal mining market	21	4
		16. MSHA approval requires revealing proprietary information	1	23
		17. Approval of technology is often required for small design or part changes	14	8
	Mine operator burden	18. Exceeding minimum safety requirements opens mine operators to citation for failure of nonrequired features	6	13
		19. Exceeding minimum safety requirements can reveal unknown risks	2	21

Barrier Group	Barrier Subgroup	Barrier	Number of Interviews	Citation Ranking
		20. The regulatory burden of operating some technologies dissuades mine operators from using them	1	23
	Regulatory culture	21. Conservative and risk-averse culture	13	10
Other	Cultural	22. Mine operators are resistant to change	11	11
	Liability	23. Greater liability risk in U.S. compared to other countries acts as disincentive to enter market	4	17
	Federal support	24. No federal agency is addressing mining technology needs	5	14

NOTE: Rankings are tied for barriers mentioned the same number of times.

Below, we discuss each of these barriers in more detail. Unless otherwise noted, the material presented is drawn directly from interviews.

Economic Barriers

We identified six barriers that we grouped as stemming from economic factors, which we further divided into three subgroups: insufficient demand, insufficient supply, and specialized market. All of these barriers are related to the small and shrinking size of the underground coal mining market.

Insufficient Demand

1. Small U.S. market makes it difficult for suppliers to recoup investments in new technology

Most of the technology suppliers noted that the small size of the available market created a disincentive to invest resources in innovation. This was the second most commonly cited barrier in our interviews (Table 3.3). A common assertion was that, even if every underground coal mine bought as many as it could use of whatever new technology the supplier was considering developing, the sales revenue would not be enough to recoup the investment that would have been needed to develop the new technology.

Many suppliers explained that the small and shrinking underground coal market was driving them to pursue new customers in other industries. Several companies that historically considered underground coal mining as their primary market had shifted partially or almost completely to other markets. As one supplier put it, "Coal mining sales for the vast majority of our history, say through 2015, were 80 percent to 90 percent of revenue; now it's 20 percent to 30 percent, if that. We have no desire, whatsoever, to develop any new products for the underground coal mining industry." Another supplier summarized a common sentiment in saying, "If we weren't in it, we probably wouldn't pursue it." Others were more blunt: "If I was a supplier, I wouldn't spend a dime on underground coal mining," and, "No one in their right mind would be in this market. You would never do it if it was your own money. If you looked for a business loan, the bank manger would throw you out."

This barrier is well illustrated by the situation with the availability of surveying equipment. Surveying equipment transitioned from manual to electronic several decades ago, yet there is currently no electronic surveying equipment approved for use in underground coal mining on the market. In fact, the last (and possibly only) approved electronic surveying device was retired by the supplier in the 1980s. Evidently, no suppliers deem it worthwhile to develop a product for this market. As a result, mine operators must either use manual surveying equipment or seek permission from MSHA to use nonapproved electronic surveying equipment. Few, if any, suppliers still provide or support manual surveying equipment, making that option increasingly difficult to pursue. The market has thus left the industry in the difficult position of relying on nonapproved technology for something as essential as surveying.

Suppliers of general technologies such as surveying equipment have large markets in other industries and hence can choose to move out of underground coal mining with relative ease. However, for suppliers of technologies that are unique to underground coal mining, such as most coal production equipment, moving to new industries might not be an option.

2. Shrinking market leads to incumbent dominance

Beyond the small size of the market, the fact that it is shrinking (see Figures 1.1–1.3) led technology suppliers to note that there are no new customers among mine operators and that existing customers are disappearing. Existing customers have long-standing relationships with existing suppliers. Having no new entrants on the demand side reduces the opportunity for new entrants in the technology supplier side to gain a foothold in the market.

3. Mine operators lack funds to invest in new technology

Mine operators expressed concerns about having decreasing revenue, forcing them to cut costs. This results in mine operators having few resources to invest in new technology. Some participants noted that, even if the investment may reduce operating costs over the long term, up-front investment funds are often not available.

4. Unwillingness to exceed regulatory requirements for safety technology

With regard to technologies specifically focused on worker safety, some interview participants claimed that worker safety is not an inherent driver for the technology market. This was far from a consensus view, with some feeling that regulatory requirements represent a minimum standard and that an argument could be made that exceeding the regulatory requirements with innovative safety technologies could increase a company's competitiveness. In practice, however, our interviews revealed that mine operators will generally invest only in safety technologies that are specifically mandated by regulation. Reasons cited for this position are that worker safety is so highly regulated that employers think that the regulatory system acts as a de facto safety and health program, that the coal market is in a poor state, and that the workers' compensation system largely shields employers from the cost of worker injuries.

Insufficient Supply

5. Technology developers lack resources to commercialize

In parallel with reducing demand for new technology, the shrinking coal market in the United States has also stifled innovation through reduced revenues for technology suppliers. As with mine operators, technology suppliers are facing shrinking sales, forcing them to reduce costs. This reduces the resources available to innovate and commercialize new technologies. Further, limited available innovation resources are being focused on pursuing alternative markets where there are signs of growth.

Specialized Market

6. Harsh physical environment in mines dissuades potential developers

The underground coal mining environment is unusual in that it places special physical demands on technology. This makes the market specialized, and some interview participants speculated that this specialization dissuades new entrants who are unfamiliar with the demands. We note that this barrier is closely associated with the specialized regulatory requirements of underground coal mining technology discussed below, and it may be difficult to distinguish the two.

Regulatory Barriers

Interview participants described 15 barriers stemming from regulatory issues, making regulatory barriers the most common group of barriers by a wide margin. Although states have important regulatory oversight over many aspects of underground coal mining, the majority of regulatory requirements related to technology commercialization and adoption come from the federal government through MSHA, and all the barriers raised in our interviews stem from the federal regulatory environment.

MSHA's regulatory role with regard to underground coal mining is extensive, but the primary area relevant to this study is the approval of technology for use in hazardous atmospheres. Any electrically powered technology used within the active working areas of an underground coal mine must be *permissible*, meaning that it has been certified to be compliant with particular safety standards intended "to assure that such equipment will not cause a mine explosion or mine fire" and "to prevent, to the greatest extent possible, other accidents in the use of such equipment" (Code of Federal Regulations, Title 30, Section 75.2). The standards were developed by MSHA or its predecessors, and all technologies used in such permissible areas must be approved for use by MSHA. This requirement applies to any electrically powered equipment for use in hazardous atmospheres, whether it be for coal production or support activities, such as atmospheric monitoring, computing, communications, transportation, or lighting.

Other environments in which workers may encounter hazardous atmospheres, such as petroleum, shipyards, and agriculture, also have safety requirements for equipment. However, these industries are regulated by the Occupational Safety and Health Administration (OSHA), which uses a regulatory approach in which equipment must meet voluntary consensus standards (VCSs) that closely align with internationally recognized standards and does not need to be approved by OSHA.

The 15 regulatory barriers fall into six subgroups, reflecting different aspects of the MSHA approval process: cost, duration, currency of regulations (i.e., how current the regulations are), prescriptiveness of standards, mine operator burden, and regulatory culture (meaning the prevalent attitudes and practices in the regulatory environment).

Approval Cost

7. Cost of technology approval dissuades developers

Obtaining approval for new technology entails an expense for technology suppliers. Costs include the time required to prepare the initial application and revisions to the application in response to feedback from MSHA, the resources required to redesign the technology in response to feedback from MSHA, and the MSHA application fee. Because the extent of revision and redesign required to obtain approval is unknown, the total cost is uncertain, making it difficult to account for in project planning. These costs can dissuade technology developers under certain conditions. One such situation is that suppliers considering developing a first-of-a-kind technology thought that the cost of seeking MSHA approval was too uncertain to merit moving ahead. Another is that suppliers with stable revenue in non-U.S. underground coal mining markets noted that the cost of obtaining MSHA approval was not worth it to them. A third situation is that, given anticipated sales revenue resulting from a new technology development effort, the added cost of MSHA approval is sufficient to shift the effort from profitable to unprofitable. Finally, some small companies noted that the cost of MSHA approval was unaffordable. All of these situations are exacerbated by the relatively small size of the U.S. market, which minimizes the potential sales revenue that would be gained with approval.

In addition to acting as a barrier to technology commercialization, the cost of MSHA approval may be a barrier to technology adoption. Mining company representatives noted that MSHA approval costs increase technology prices for customers, with one estimating that an MSHA-approved product costs mine operators three or four times more than a comparable non-MSHA-approved product.[4]

Multiple MSHA representatives confirmed that the cost to applicants of the technology approval process may dissuade investment in new technology development and commercialization. It should be noted that any regulatory process to ensure the safety of equipment used in hazardous working conditions will entail costs, and we did not ask representatives for their experiences with the relative costs of different systems.

Approval Duration

8. Duration of technology approval dissuades developers

A barrier closely related to the cost of MSHA approval and often cited in conjunction with it is the duration of the MSHA approval process. This was the most commonly cited barrier in the study

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[4] This estimate likely depends on the total cost of the technology in question (i.e., the proportional price increase resulting from MSHA approval costs will be greater on low-cost items than on high-cost items).

(Table 3.3). Many interview participants stated that the generally long and uncertain duration of the MSHA approval process frustrates product development and business planning efforts. Several technology suppliers that work in multiple countries noted that approval of their technology in the United States under MSHA takes much longer than the approval of similar technologies in other countries. Interviews revealed multiple ways in which approval duration presents a barrier to innovation and commercialization.

Many participants claimed that the involved and time-consuming approval process stifles innovation and drives potential new entrants "to industries with no or less onerous approval requirements." Experiences with the time required for approval ranged from one to six years.[5] And because MSHA's standards and approval process are not harmonized with those of other countries, there is no assurance that a technology's existing approval for use in other countries will influence the approval duration. Some participants stated that the uncertainty in the approval process is as great a barrier as the length. One noted that if they knew how long the duration would be, they could plan around it, but the combination of slowness and unpredictability is very difficult to work with.

Multiple MSHA representatives confirmed that the long and involved technology approval process dissuades investment in new technology development and commercialization.

Another way in which the long approval duration presents a barrier is that it makes it difficult to keep technology current. Once a technology is approved, changes to the design or components often require a new approval, which suppliers are reluctant to undertake. As a result, approved technologies can be quasi-static and not updated as the state of the art evolves.

9. Technology approval applications are canceled when more than minor discrepancies are found

A recent change in MSHA's technology approval process may extend the approval process for some applicants. Prior to the change, after reviewing an application, if the technology was not approved, MSHA presented the applicant with a list of discrepancies that needed to be addressed to obtain approval. Upon the applicant addressing the discrepancies, MSHA would immediately review the revised application. This cycle could be repeated multiple times.

In response to applicant feedback and suggestions, MSHA revised its policy in late 2019. Under the new system, all applications are closed after one review.[6] Applicants that fail are provided with a list of discrepancies and may then reapply for approval with a new application. The essential difference is that, prior to the change, an application review would remain active until the technology was approved or the application was withdrawn. Since the change, an application that fails is "sent to the end of the line."

MSHA's rationale for this change, described both in a letter to technology suppliers and in interviews with us, was to streamline the application process. Applications from underprepared applicants or that otherwise required substantial revision were tying up MSHA investigators for long periods, creating a large backlog of new applications waiting for review. Hence, this new policy may expedite approvals for many applicants. At the same time, several technology suppliers complained

[5] MSHA representatives noted that MSHA has consistently hit its goal of 80 percent approvals within 120 days for the past three-plus years. They also noted that the duration depends on the responsiveness of both applicants and MSHA.

[6] Applications with minor discrepancies may be given a single opportunity to quickly revise the application.

that this will make the approval process even longer for any complex or first-of-a-kind technology, which would typically involve multiple iterations. Because this change is relatively recent, the net impact of this policy change is unknown.

10. Lack of transparency about technology approval application status

Some technology suppliers claimed that a lack of transparency about the status of their technology approval applications added to the length of the approval process. Although suppliers praised MSHA's willingness to provide guidance about preparing an application, they noted that, once an application has been submitted, MSHA does not provide feedback on the application status. Therefore, applicants have no insight into the shortcomings of an application until the review is complete and MSHA presents the discrepancies. Suppliers noted that this can occur years after the application was submitted, during which time they could have been working on addressing discrepancies if MSHA had notified them as soon as the discrepancies were identified.

MSHA representatives indicated that investigators typically do inform applicants of major discrepancies as soon as they arise but generally refrain from providing feedback on each issue as it arises, because this would likely cost more money, take more time, and create a confusing piecemeal review process. They also noted that many applicants do not want piecemeal feedback.

11. Poor coordination between MSHA and NIOSH

Although NIOSH generally has no formal regulatory role related to underground coal mining technology, it does have a role in the testing of at least one particular technology type as part of the MSHA approval process. Technology approval therefore requires coordination between MSHA and NIOSH. Developers of this technology type felt that the required coordination between agencies was poor and extended the duration of the already protracted approval process.

Currency of Regulations

12. MSHA standards are out-of-date

A commonly cited barrier to getting current technology into underground coal mines is that MSHA technology approval standards are very out-of-date. One reason for this is that MSHA standards are embedded in regulations. Changing a standard therefore requires a formal rulemaking process, which triggers an involved series of actions, including a regulatory analysis, soliciting and responding to public comment, and approval from the Office of Management and Budget in some cases. Doing so requires substantial attention and resources. MSHA must prioritize limited resources to regulatory concerns that go well beyond updating technology approval standards, and many standards have fallen out-of-date. As one participant put it, "MSHA only goes to rulemaking when it's a big deal. It tends not to deal with lesser issues."

As a result, several aspects of technology approval are based on knowledge and best practices that are many years or even decades out-of-date. Interview participants noted several examples of technology standards that have remained unchanged since the early 1970s.[7] An implication of this is that, to receive approval, underground coal mining technologies require features and capabilities that are obsolete, which hinders effective design and increases size and cost. For example, one interviewee noted that electric motors must possess certain features—such as the ability to reset circuit breakers without opening enclosures, isolating control and motor circuits, and particular maintenance capabilities—that are no longer always applicable to newer technologies.

MSHA representatives acknowledged that outdated regulations are a problem. One noted, "We have approval regulations still on the books that were promulgated in the 1930s. . . . Our inspectorate is saddled with the 1968 version of the electrical code." He noted that MSHA has limited resources for updating regulations, and as a result such efforts target more-urgent matters, such as black lung and silica.

13. MSHA regulatory environment is unequipped to address new technology

A related barrier to the commercialization of new technologies is that, through a combination of being out-of-date and prescriptive, "the system is not welcoming to new technology," according to one

[7] Examples include the following:

- Code of Federal Regulations, Title 30, Part 7, Section 7.304 (Technical Requirements) incorporates American Welding Society Standard AWS D14.4-77, Classification and Application of Welded Joints for Machinery and Equipment, 1975.
- Code of Federal Regulations, Title 30, Part 56, Section 56.5005 (Control of Exposure to Airborne Contaminants); Part 57, Section 57.5005 (also called Control of Exposure to Airborne Contaminants); and Part 72, Section 72.710 (Selection, Fit, Use, and Maintenance of Approved Respirators) incorporate American National Standards Institute Standard (ANSI) Z88.2-1969, American National Standards Practices for Respiratory Protection, 1969.
- Code of Federal Regulations, Title 30, Part 56, Section 56.12047 (Guy Wires) incorporates National Electrical Safety Code, Part 2, Safety Rules for the Installation and Maintenance of Electric Supply and Communication Lines, 1961.
- Code of Federal Regulations, Title 30, Part 56, Section 56.13030 (Boilers) incorporates the American Society of Mechanical Engineers Boiler and Pressure Vessel Code, 1977, and the National Board Inspection Code, 1979.
- Code of Federal Regulations, Title 30, Part 75, Section 75.1730 (Compressed Air; General; Compressed Air Systems) incorporates the American Society of Mechanical Engineers Boiler and Pressure Vessel Code, 1971.
- Code of Federal Regulations, Title 30, Part 57, Section 57.5001 (Exposure Limits for Airborne Contaminants) and 70.1900 (Exhaust Gas Monitoring) incorporate the American Conference of Governmental Industrial Hygienists standard Threshold Limit Values for Chemical Substances in Workroom Air, 1973.
- Code of Federal Regulations, Title 30, Part 71, Section 71.700 (Inhalation Hazards; Threshold Limit Values for Gases, Dust, Fumes, Mists, and Vapors) incorporates the American Conference of Governmental Industrial Hygienists standard Threshold Limit Values of Airborne Contaminants, 1972.
- Code of Federal Regulations, Title 30, Part 57, Section 57.5047 (Gamma Radiation Surveys) incorporates American National Standards Standard N13.8-1973, Radiation Protection in Uranium Mines, 1973.
- Code of Federal Regulations, Title 30, Part 57, Section 57.13030 (Boilers) incorporates the ASME Boiler and Pressure Vessel Code, published in 1977, and the National Board Inspection Code, 1979.
- Code of Federal Regulations, Title 30, Part 71, Section 71.602 (Drinking Water; Distribution) incorporates the National Plumbing Code (ASA A40.8), 1955.
- Code of Federal Regulations, Title 30, Part 75, Section 75.1107-4 (Automatic Fire Sensors and Manual Actuators; Installation; Minimum Requirements) incorporates the National Fire Protection Association National Fire Code No. 72A, Local Protective Signaling Systems, 1967.
- Code of Federal Regulations, Title 30, Part 75, Section 75.1719-2 (Lighting Fixtures; Requirements) incorporates the Institute of Electrical and Electronics Engineers, Inc., Standard No. 32-1972, 1972.

interview participant. Regulations apply specifically to particular pieces of technology used for specific purposes, in many cases in ways that are no longer in practice. Multiple interview participants highlighted that a source of reluctance to develop or introduce new technologies is that it is unclear what part, if any, of the regulation is relevant to the new proposed technology. One technology supplier, in a preapplication consultation with MSHA about the relevant regulatory requirements of a potential new product, said that MSHA told them that, because it had not seen any technology similar to the proposed idea before, it was not able to provide any guidance until it had some experience from going through the approval process with an applicant. In effect, MSHA wanted a test case before advising about how to approach an application. Although perhaps understandable, the case suggests that MSHA perceives the technology approval process to be as unadaptable as applicants do.

Interview participants attributed this challenge with approving new technologies to a reluctance to apply or to failed approval applications. Examples cited range from lithium-ion batteries to automation to novel roof control technologies. One mine operator also noted that, among mine operators, there is a "reluctance to be first because of perceived heightened scrutiny and challenges from MSHA for a first adopter."

It should be noted that the challenge of shepherding a new technology through the regulatory approval system is not a new problem. Until 2002, only low- and medium-voltage longwall shearers were permitted under MSHA regulations. However, the first high-voltage longwall shearers entered the market in 1985 (MSHA, 2002). Because they could not meet MSHA regulations, they were brought into service through a regulatory alternative known as a *petition for modification of mandatory safety standards*—this is informally called a *101(c) petition*, which refers to the section of the Federal Mine Safety and Health Amendments Act that prescribes the process (Pub. L. 95-164, 1977, Section 101[c]). This process allows a mine operator (not a technology supplier) to petition MSHA to be allowed to modify the requirements of an existing MSHA safety standard to achieve the purpose of the standard by means different from those required by the standard (Code of Federal Regulations, Title 30, Part 44). Over the next 16 years, MSHA granted more than 100 101(c) petitions to use high-voltage longwall shearers (MSHA, 2002). In 2002, MSHA completed a revision to the regulation to allow high-voltage shearers to be approved through the normal process.

A nearly identical sequence of events occurred between 1997 and 2010 for high-voltage continuous mining machines (MSHA, 2010). In both cases, the reasons that the new technology was not able to be approved were that (1) the regulation was written very prescriptively around the existing technology at the time and (2) the regulation was not updated as new technology emerged.

These examples are notable for a few reasons. First, the technologies in question were not particularly novel or revolutionary and yet still faced barriers. Second, because it is unclear whether all 101(c) petitions will be granted, there is risk either to the supplier of developing a new technology that it will not be able to sell or to the mine operator of investing in a new technology that it will not be able to use.[8] Finally, such widespread and long-term use of a laborious and risky petition approval process nominally designed for special cases, even if it became streamlined through repeated use, is tacit acknowledgment that the technology is at least as safe as the existing standard and, therefore, that the

[8] We do not know whether final sales were contingent on approval of a 101(c) petition or whether customers bought the technology outright without knowing whether they would be allowed to use it. In other words, it is not clear who was left "holding the bag" if the petition was not approved.

technology's inability be approved through the normal approval process has little to do with safety concerns.

One factor that might have made this approach less laborious and risky than it sounds is that the suppliers might have already developed the technologies for markets in other countries with more-flexible and more-receptive technology approval systems. Thus, suppliers did not necessarily develop the technology entirely for a U.S. market for which approval was uncertain.

Prescriptiveness of MSHA Standards

Interview participants repeatedly called out the highly prescriptive nature of MSHA standards and several barriers that this creates.

14. Prescriptiveness crowds out novel approaches

A general observation about the prescriptiveness of MSHA regulations is that they can be so specific to existing technology that they effectively crowd out novel approaches. Best practices and federal policy for standards development is to develop standards that specify performance characteristics (performance-based standards) as opposed to design and construction characteristics (prescriptive standards) (U.S. Office of Management and Budget, 2016). Although MSHA regulations do include some performance-based standards, such as mandating permissible exposure limits (PELs) for respirable coal dust and silica, interview participants nonetheless raised concerns about the prescriptiveness of MSHA standards.

One participant stated, "MSHA is tied to out-of-date, overly prescriptive legislation that doesn't allow for safety solutions other than those specified." Another said that MSHA had informally told him that, if the design of a technology meets the construction requirements, it will get approved, effectively implying that the approval system weights prescriptive factors more than performance.[9]

One interview participant highlighted examples of specific required design details, such as bolt spacings and flange widths, which he viewed as unnecessarily prescriptive. Others highlighted the impact of prescriptiveness specifically on the development of novel safety technologies. Because regulatory requirements for protecting worker safety are so strictly prescribed, any technology designed to improve worker safety that is not "counted" within the regulatory framework is unlikely to sell. As a result, technology suppliers have little incentive to develop and commercialize novel approaches to safety.

One example of this is personal protective equipment, such as powered air-purifying respirators, that reduce workers' exposure to dust. MSHA regulations regarding dust levels do not account for the effect of personal protective equipment, and, hence, any exposure reduction to an individual worker from a powered air-purifying respirator is not considered for dust exposure limits.

Another example is safety approaches that focus less on engineering and more on training and practices, such as the National Mining Association's CORESafety principles (CORESafety, undated). One participant noted that the adoption of such approaches is known to be associated with improved safety, yet they are not recognized in the MSHA regulations. A third example we heard about was that a regulation requiring that methane measurements be made manually creates a disincentive to

[9] MSHA approval requires performance testing.

develop automated methane detection technology, even though automated technology may be desired and beneficial.

One somewhat special case is related to a continuous personal dust-monitoring technology that was being developed in conjunction with a new MSHA regulation mandating the use of that technology (Code of Federal Regulations, Title 30, Part 74). Because the regulation and technology were developed together, the details of the regulation are closely tied to the details of the technology, essentially requiring any new entrant to produce a nearly identical technology.

15. MSHA-specific standards isolate U.S. underground coal mining market

Several interview participants noted that MSHA's technology approval system is an outlier in the global coal mining market. Other countries with major coal mining markets use a similar set of VCSs rather than government-unique standards. These standards are developed through a consensus-based process that includes representatives from relevant market stakeholders and technical experts. This process ensures that a standard reflects the needs of all stakeholders and the most current research and other knowledge. VCSs are, by themselves, voluntary and unenforceable, but government agencies routinely adopt VCSs by reference into regulations, making them mandatory for the regulated population.

Most relevant VCSs for underground coal mining technology are produced by the International Electrotechnical Commission (IEC). These standards are adopted by reference into mining safety regulations by regulatory agencies around the world. Agencies typically include *country deviations* when adopting IEC standards, although these deviations are relatively minor, such that, outside the United States, there is a largely uniform regulatory framework for underground coal mining technology.

Although MSHA regulations do reference several VCSs, these are primarily related to issues other than the fire and explosion hazards in environments such as underground coal mines. For the latter, MSHA regulations rely on MSHA-specific standards.

One implication of this situation is that MSHA standards are developed in relative isolation from the national and international standards development communities. MSHA representatives confirmed that MSHA "does not collaborate in rulemaking; it's not like the process for VCSs." As a result, MSHA does not necessarily incorporate input from all relevant stakeholders or follow best practices for standards development, such as ANSI's essential requirements (ANSI, 2021).[10] For example, most standards development organizations and regulatory bodies, as well as U.S. policy for federal agency standards, support developing standards based on performance criteria rather than design criteria, when appropriate (U.S. Office of Management and Budget, 2016).

A second implication is that, because MSHA standards are different from those used in the rest of the world, technology suppliers effectively must produce a separate product for the U.S. underground coal mining market. This creates a disincentive for technology suppliers to coal mining operations in other countries to enter the U.S. market. Several such suppliers expressed frustration with the

[10] MSHA rulemaking procedures must adhere to notice-and-comment and other requirements contained in such statutes as the Administrative Procedure Act (Pub. L. 79-404, 1946), the Small Business Regulatory Enforcement Fairness Act (Title II of Pub. L. 104-121, 1996), and the Congressional Review Act (part of Pub. L. 104-121 and codified as U.S. Code, Title 5, Sections 801–808).

challenge or inability to get products that are approved and well accepted in other countries approved for use in the United States. Some suppliers simply decline to attempt approval. For example, following a supplier's decision to permanently cease production of a popular MSHA-approved helmet with an integrated powered air-purifying respirator, a supplier of a similar product approved in several other countries opted not to seek MSHA approval, deciding that, even with nearly assured new sales in the United States, it was not worth the time and cost that MSHA approval would require. As a result, this technology is no longer available to the U.S. underground coal mining industry, other than through a case-by-case 101(c) process pursued by a mine operator.

This problem extends beyond technology specific to coal mining to include technology for other U.S. industries. OSHA, which regulates safety in most U.S. industries other than underground coal mining, incorporates ANSI/UL and ANSI/ISA 60079-series standards (OSHA, undated-a), which are similar to the IEC standards (International Electrotechnical Commission System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres [IECEx], undated-b).[11] This means that suppliers of technology for other U.S. industries with hazardous atmospheres (e.g., petroleum) must also often produce separate products for underground coal mining. This affects a wide variety of products, such as sensors, lights, radios, and tablets. Thus, MSHA's go-it-alone approach requires that virtually any product used in the permissible areas of U.S. underground coal mines be specially designed and produced specifically for that market.

This barrier was highlighted in a National Research Council report on improving self-escape from underground coal mines, which called for

> convening a joint industry, labor, and government working group to identify a range of mechanisms to reduce or eliminate any barriers to technology approval and certification, which should include exploring opportunities to cooperate with other international approval organizations to harmonize U.S. and international standards without compromising safety. (National Research Council, 2013)

In an effort to alleviate some of the barriers associated with MSHA-specific standards, MSHA in 1994 proposed and in 2003 promulgated a rule that "permits manufacturers to have their products approved based on non-MSHA product safety standards once MSHA has determined that the non-MSHA standards are equivalent to MSHA's applicable product approval requirements or can be modified to provide at least the same degree of protection as those MSHA requirements" (MSHA, 2003; see Code of Federal Regulations, Title 30, Part 6). Although seemingly a major reform, in practice this rule has had almost no impact. The main reason for this is that MSHA has thus far determined equivalency for only two non-MSHA standards (IEC standards 60079-0 and 60079-1) and has imposed so many modifications that the adopted versions of these standards are, according to interview participants, nearly as prescriptive and cumbersome as the original MSHA standards (MSHA, 2006; Code of Federal Regulations, Title 30, Part 6). According to MSHA representatives, this rule "has failed." "Maybe one or at most two" approvals have been granted using these modified non-MSHA standards since they were approved for equivalency in 2006.

[11] UL stands for Underwriters Laboratories. According to MSHA, "The ANSI and IEC standards on particular topics are generally similar but not identical, as the ANSI standards include modifications of the IEC standards and U.S.-specific requirements (U.S. deviations)" (MSHA, 2020a).

More recently, in 2020 MSHA proposed a new rule that would accept six IEC standards and eight ANSI standards that provide protection against fire or explosion dangers in place of MSHA's existing approval standards in its regulations (MSHA, 2020a). The proposed rule, which cites NIOSH work on the equivalency of ANSI and MSHA standards (Calder, Snyder, and Burr, 2018), incorporates the ANSI and IEC standards in their entirety, without modification. The public comment phase of the rule closed on December 21, 2020; however, no further information has been released since.[12] NIOSH incorporated the interview results from our study into its formal comments to the proposed rulemaking. If promulgated, this rule could have a major impact on the ability to incorporate modern technology in U.S. underground coal mines.

Appendix C presents an expanded comparison of the testing, evaluation, and approval regimes for electric equipment in underground coal mines among different countries.

16. MSHA approval requires revealing proprietary information

One mine operator said that some technology suppliers are unwilling to seek MSHA approval because of concerns about the need to submit proprietary information to MSHA. That operator claimed that this was one reason that large information technology suppliers, such as Apple, are not involved in the market. Although raised only once, this appears to be a barrier to at least some technology suppliers that do not wish to reveal proprietary information to the federal government. MSHA representatives indicated that MSHA does not release approval holders' proprietary information.

17. Approval of technology is often required for small design or part changes

An implication of the prescriptiveness of MSHA's standards and technology approval process is that changes to the design or components of an approved technology often require a new approval. As noted above, in the "Approval Duration" section, several interview participants said that the time and overall burden of obtaining such a new approval creates a disincentive to making any changes to approved technologies unless absolutely necessary. As a result, underground coal mining technologies tend to be "locked in" to the state of the art at the time they were approved and not updated as technology evolves. Participants emphasized that the requirement for approval of changes is overly prescriptive, including such changes as brands or models of LED bulbs and batteries, and applies even if a supplier only slightly revises or even simply updates the name or model number of a component. Although this barrier affects all types of technology, it is particularly problematic in areas of rapid development, such as information technology, where technology evolves so rapidly that approved products can quickly become outdated or obsolete.

Applying for approval of changes carries risks beyond the barrier of wanting to avoid the time and cost of the MSHA approval process. One technology supplier described a case in which, upon the supplier's submission of an application for approval for certain specific modifications, the MSHA reviewer rejected other aspects of the design that had already been approved by a different MSHA investigator during the original approval process. MSHA representatives confirmed that such a scenario is possible.

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[12] Comments are available at MSHA, 2020b.

As an example of the lengths technology suppliers will go to to avoid undertaking the MSHA approval process, one technology supplier has twice acquired suppliers of components essential to its approved technology that were on the brink of going out of business just so that it could sustain access to those components and stay compliant with its existing MSHA approvals. One of those components is a relay used on a device that received MSHA approval in the 1970s. In essence, the approval process is so involved and time-consuming that the industry goes out of its way to continue to operate with outdated technology to avoid facing the approval process. This results in widespread use of outdated technologies in underground coal mining. In some particularly fast-moving technology areas (e.g., LED bulbs), the long approval time leads to situations in which technologies can literally "be obsolete before they're approved," according to interview participants.

Mine Operator Burden

Beyond barriers to the development and commercialization of technologies, our interviews revealed regulatory-related issues that act as barriers to the use of approved technologies by mine operators.

18. Exceeding minimum safety requirements opens mine operators to citation for failure of nonrequired features

Several interview participants expressed frustration with the risk of being cited for a violation related to voluntarily employing safety technologies that surpass the minimum regulatory requirements (i.e., the operation is fully compliant without the voluntary technology). This risk, they claimed, creates a disincentive to invest in safety and health technology that goes beyond the minimum regulatory requirements. This barrier applies to both the adoption of available technologies and the development of new technologies. One example relayed by a mine operator involved a potential backup lighting system. The mine operators had considered installing redundant lights on a piece of equipment so that operations could continue if a light failed. However, the operators chose not to proceed because they were concerned that operating the equipment with a failed light (even though the equipment would be operating with compliant lighting) would open them up to a citation for an equipment violation. Another example involved a mine operator being cited for an inoperable emergency escape capsule because they kept a second capsule on site (only one is required) for spare parts.

MSHA representatives explained that citations for noncompliance associated with optional technologies are possible and justified when the issue represents a safety hazard.

19. Exceeding minimum safety requirements can reveal unknown risks

Another barrier to the adoption of nonrequired safety technology is that, according to some mine operators, using more than the minimum required amount of detection equipment might lead to the discovery of hazards that could halt operations or result in violations that otherwise might have gone undetected. For example, one mine operator noted that increasing the number of points at which methane measurements are taken increases the chances of discovering conditions that exceed allowable levels. It is unclear whether mine operators believe that exceeding allowable methane levels is a small enough risk that they are not concerned for the workers' safety or that market conditions are so poor that they are willing to risk worker safety to avoid costly delays or citations.

20. The regulatory burden of operating some technologies dissuades mine operators from using them

In some cases, MSHA regulations impose certain requirements on the use of particular technologies. This leads some mine operators to not use some available technologies, even if they are potentially beneficial to operations. This barrier was raised in the context of mine-wide monitoring systems, for which documentation requirements (associated with siting, inspections, maintenance, etc.) were viewed to expose the mine operator to the risk of citation for violation and be such a burden that some mine operators opt to not adopt them.

Regulatory Culture

21. Conservative and risk-averse culture

A final aspect of the regulatory environment that interview participants highlighted as a barrier was the culture at MSHA. Most of the technology suppliers and many of the mine operators that we interviewed have experience with regulatory environments outside U.S. underground coal mining and said that working with MSHA in relation to underground coal mining was far more difficult than working in other regulatory settings. Descriptions of concerns varied, but the overall sense was that MSHA's approach is conservative and risk-averse and that it takes an adversarial approach to regulation and enforcement. Expressions of frustration were very common, with interview participants describing MSHA and the approval process with such terms as "bureaucratic," "painful," "unpredictable," "inconsistent," "overbearing," "onerous," "unbelievable," "dysfunctional," "tribal," "insular," "inflexible," "meddling," "out of touch," "intransigent," "stifling," "nontransparent," "not welcoming," "completely broken," "disaster," "nightmare," "driven by power," and "center of the universe."

One participant said that representatives from MSHA had told him that "MSHA is the worst detriment to new technology coming into the industry." Another claimed that "MSHA approval engineers have little oversight, and applicants are fearful of retaliatory behavior. The government has them under their thumb." Other examples participants cited include MSHA's general unwillingness to waive certain regulatory requirements at its discretion (as is sometimes allowed in the regulations),[13] its unwillingness or inability to update regulations to bring them in line with current technology, the lack of transparency about an application's status, the ability for an investigator on an application for approval of a modification to overturn prior approvals, inconsistent application of approval requirements, and an unwillingness to tackle applications for novel technologies that do not fit into the current regulatory structure.

Some participants thought that MSHA's hands are tied by the specificity of the Federal Mine Safety and Health Amendments Act of 1977 and associated code of federal regulations, while others

[13] For example, Code of Federal Regulations, Title 30, Part 18, Sections 18.30, 18.62(a), 18.66(a), 18.82(b)(iii), and 18.93(b); Code of Federal Regulations, Title 30, Part 27, Sections 27.20 and 27.35; Code of Federal Regulations, Title 30, Part 33, Sections 33.21 and 33.37(d); and Code of Federal Regulations, Title 30, Part 74, Section 74.7(b)(6).

echoed one interview participant's claim that "MSHA hides behind the Mine Act." Although we have not conducted an analysis of the act or the associated federal regulations (Title 30), we note that Sections 101 and 508 of the act grant MSHA broad authority to define standards for permissibility (Pub. L. 95-164, 1977).

Other

Although the majority of barriers raised in the interviews stem from economic and regulatory issues, participants raised a few additional barriers that fall outside these categories.

Cultural

22. Mine operators are resistant to change

Although our analysis revealed multiple reasons why mine operators may be reluctant to invest in new technologies (limited resources, unwillingness to exceed regulatory requirements, and regulatory burdens associated with operating some technologies), according to several participants, mine operators are also often unwilling to explore new technologies because of a general resistance to change. Resistance to change is subjective and difficult to separate from other barriers to technology adoption but was cited specifically and in the context of all technology types (i.e., not just safety technology). We therefore include resistance to change as a distinct barrier. Some suppliers claimed that this resistance persists even in the face of evidence for economic and productivity benefits.

Participants offered few insights into the source of this resistance, but noted that it is most prominent among older workers and in association with digital technologies. Suppliers said that this resistance to adoption has upstream impacts by reducing the incentive to develop and commercialize new technologies.

Such resistance to change, particularly among older workers in relation to digital technologies, is likely not specific to underground coal mining, but rather a barrier common to many industries. However, its effects will be stronger in a shrinking market where there are decreasing numbers of young workers entering the workforce.

Liability

23. Greater liability risk in U.S. compared with other countries acts as disincentive to enter market

Some technology suppliers of underground coal mining technology that operated overseas noted that one reason they were reluctant to enter the U.S. market is that there is a greater risk of liability losses in the U.S. market relative to others. The extent to which this is true is impossible to substantiate without some dedicated analysis, which is out of scope for this research. However, even if the risk is no more than a perception, it may act as an actual barrier.

Federal Support

24. No federal agency is addressing mining technology needs

Several interview participants noted that no federal agency is pursuing or supporting advances in mining technology overall. Although NIOSH's work was generally viewed positively, participants noted that it is restricted to protecting worker safety and health and does not address coal production technologies more generally. Some interview participants lamented the passing of the U.S. Bureau of Mines in this respect. The responsibility for mining-production-related technology research was transferred to Department of Energy in 1996, and funding was subsequently reduced to a level that the research program was effectively abandoned.

The general view from industry is that the Bureau of Mines had the mining industry's best interests at heart, while MSHA and NIOSH are statutorily required to prioritize the safety and health of mine workers and may even impede progress. As one participant put it, "Agencies need to work with industry to help rather than hinder." The loss of the Bureau of Mines was not only a loss of support to technology development; restricting federal support to safety and health has created barriers to the industry's trust in and receptiveness to NIOSH. One participant noted that when he was with the Bureau of Mines, mine operators were generally receptive to the bureau's requests to test technology in mines. However, mine operators are wary of helping NIOSH test technology because of the possibility that they may be supporting the development of another mandatory regulatory burden. As another participant put it, there is a need for collaboration between government and industry "without agendas" related to new regulatory requirements.

Workshop Results

The eight workshop participants included representatives from five of the stakeholder organization types listed in Table 3.2: legal, mining company, regulatory, technology supplier (major equipment), and technology supplier (other). These include the four most frequent organization types included in the interviews and therefore reflect a reasonably representative sample of the stakeholder community.

The workshop began with brief introductions by each participant, followed by a description of the overall project and the workshop agenda and objectives. The RAND team then described the interviews, which included a description of the methods and then a complete listing and description of the barriers that were identified.

Session 1: Clarify and Define Barriers

The first workshop session focused on reviewing the barrier taxonomy and determining whether any revisions were warranted. Overall, there was a consensus that the barriers that emerged from the interviews were an accurate and complete reflection of the barriers that exist. Although no participant had direct experience with all barriers, each barrier had been experienced by at least some of the participants, and most participants were aware of all of the barriers. There was also a sense of relief among some participants that these issues are systemic and not specific to their experience. One participant was pleased to realize, "I'm not the only one."

One participant proposed a possible additional barrier that may represent the source or cause for some of the other barriers. The proposed barrier is the existence of Subsection 101(a)(9) of the Federal Mine Safety and Health Amendments Act, which states, "No mandatory health or safety standard promulgated under this title shall reduce the protection afforded miners by an existing mandatory health or safety standard" (Pub. L. 95-164, 1977). That participant said that MSHA commonly cites this subsection as an impediment to revising regulations to accommodate new technology, claiming that it is difficult to demonstrate that a new standard will not reduce protection relative to an existing standard. Participants agreed that this mindset at MSHA contributes to a reluctance to modernize regulations.

This led to a more general discussion about how the standards in the Federal Mine Safety and Health Amendments Act are extremely outdated. They were developed in response to disasters and take a "rules and punishments" approach to safety regulation. The problem with such an approach, participants noted, is that prescriptive rules do not easily accommodate evolving empirical knowledge, technologies, and behaviors and can become inappropriate or obsolete quickly. A more modern approach, used in most other countries, is a risk-based approach, in which safety is assessed by analyzing the reduction in risk based on current information, and more of the liability for loss is shifted to industry.

This aspect of the Federal Mine Safety and Health Amendments Act, discussed under barrier 21 (*conservative and risk-averse culture*), above, clearly contributes to challenges in updating MSHA regulations. We have opted not to include it as a separate barrier, however, in part because both the interviews and the workshop discussions made clear that participants thought that MSHA has latitude in interpreting the statute and has chosen to take a conservative approach; also, we think that the more-objective implications of this rule-based aspect of the statute are adequately addressed in the existing barrier 12 (*MSHA standards are out-of-date*) and barrier 13 (*MSHA regulatory environment is unequipped to address new technology*), discussed in the "Currency of Regulations" section, above.

The remainder of the discussion entailed providing additional examples and nuances of existing barriers, but none warranted revisions to the taxonomy. Some such examples include the following: Part of the reason for the long duration of MSHA approval is that MSHA investigators are increasingly being called away to assist with accident investigations; another reason for the long durations is insufficient technical staff at MSHA, meaning that certain applications must await the availability of an appropriate MSHA engineer; and part of the reason that mine operators are resistant to change is that they have grown suspicious from repeated offerings from technology suppliers of new devices and systems that turn out to be ineffective.

Session 2: Prioritize Barriers

The second session of the workshop focused on prioritizing the barriers using the Delphi approach. As described above, barriers were prioritized according to two criteria: relative frequency of occurrence and relative magnitude.

Barrier Frequency

The results of the initial round of rating for barrier frequency are shown in Figure 3.1. Each row corresponds to a barrier and shows the number of participants who selected a given frequency rating, the total number of participants providing a rating, the average rating, and the standard deviation among the ratings. The standard deviation is a measure of the dispersion among ratings, with a lower standard deviation corresponding to less dispersion (greater consensus). The results show that some barriers—notably, barriers 8 (*duration of technology approval dissuades developers*), 1 (*small U.S. market makes it difficult for suppliers to recoup investments in new technology*), and 15 (*MSHA-specific standards isolate U.S. underground coal mining market*)—show a relatively strong consensus, whereas some others do not.

Figure 3.1. First Round Barrier Frequency Ratings

		Number of counts by rating							
		1	2	3	4	Σ	Average Rating	Standard Deviation	Avg – SD
8	Duration of technology approval dissuades developers			1	7	8	3.88	0.33	3.54
15	MSHA-specific standards isolate U.S. underground coal mining market			4	4	8	3.50	0.50	3.00
1	Small U.S. market makes it difficult for suppliers to recoup investments in new technology			5	3	8	3.38	0.48	2.89
17	Approval of technology is often required for small design or part changes		3	3	2	8	2.88	0.78	2.09
9	Technology approval applications are canceled when more than minor discrepancies are found	1	1	2	4	8	3.13	1.05	2.07
13	MSHA regulatory environment is unequipped to address new technology	1	1	3	3	8	3.00	1.00	2.00
21	Conservative and risk averse culture	1	1	3	3	8	3.00	1.00	2.00
24	No federal agency is addressing mining technology needs		4		4	8	3.00	1.00	2.00
14	Prescriptiveness crowds out novel approaches		4	2	2	8	2.75	0.83	1.92
12	MSHA standards are out of date	1	2	1	4	8	3.00	1.12	1.88
7	Cost of technology approval dissuades developers	1	2	3	2	8	2.75	0.97	1.78
4	Unwillingness to exceed regulatory requirements for safety technology	1	3	4		8	2.38	0.70	1.68
3	Mine operators lack funds to invest in new technology	2	1	4	1	8	2.50	1.00	1.50
10	Lack of transparency about technology approval application status	2	2	3	1	8	2.38	0.99	1.38
2	Shrinking market leads to incumbent dominance	3		4	1	8	2.38	1.11	1.26
20	The regulatory burden of operating some technologies dissuades operators from using them	3	1	4		8	2.13	0.93	1.20
18	Exceeding minimum safety requirements opens operators to citation for failure of non-required features	3	2	3		8	2.00	0.87	1.13
19	Exceeding minimum safety requirements can reveal unknown risks	3	3	2		8	1.88	0.78	1.09
6	Harsh physical environment in mines dissuades potential developers	3	2	1	2	8	2.25	1.20	1.05
22	Mine operators are resistant change	3	3	1	1	8	2.00	1.00	1.00
23	Greater liability risk in U.S. compared to other countries acts as disincentive to enter market	3	3	1	1	8	2.00	1.00	1.00
5	Technology developers lack resources to commercialize	4		3	1	8	2.13	1.17	0.96
16	MSHA approval requires revealing proprietary information	4	2	2		8	1.75	0.83	0.92
11	Poor coordination between MSHA & NIOSH	5	2		1	8	1.63	0.99	0.63
	Average						2.57	0.90	

NOTE: Ratings represent responses to this question: "Please provide your assessment of the relative frequency with which each of the barriers listed below comes into play across the U.S. underground coal mining market overall (4 = most frequent; 3 = more often than most others; 2 = less often than most others; 1 = least frequent)." Table cell values represent the number of responses selecting that rating; cell shading is lightest for the lowest value and darkest for the greatest value. Average and standard deviation are weighted by the number of ratings of a given value.

Figure 3.1 also shows for each barrier the difference between the average rating and the standard deviation among ratings. This difference is greatest for barriers with higher ratings and greater consensus. Therefore, this difference is a measure of priority for barriers based on their frequency of occurrence. Barriers in Figure 3.1 are sorted according to the value of this difference and hence are ranked in order of priority.

Following the Delphi method, the moderator presented Figure 3.1 to the participants and, for barriers showing poor consensus, asked for volunteers to explain their rationale for selecting disparate values. In some cases, participants' selections reflected a misunderstanding of the barrier, which was clarified in the discussion. Other times, the disparate values appeared to reflect differences in participants' experience with the barrier. Although participants were instructed to score as a representative of their industry (not just as an individual), such score dispersions may nonetheless reflect real differences in perceptions among different parts of the mining sector.

After discussing the results, participants rescored the barriers. Results for the second round of scoring are shown in Figure 3.2.[14] The average of the standard deviations among barriers decreased from 0.90 in the first round to 0.80 in the second round (11 percent), indicating a small increase in the overall degree of consensus. The change for individual barriers varied widely, including both positive and negative changes, however, indicating that the increase in consensus between rounds was not systematic across barriers.

Figure 3.2. Second Round Barrier Frequency Ratings

	1	2	3	4	Σ	Average Rating	Standard Deviation	Avg – SD
8 Duration of technology approval dissuades developers			2	5	7	3.71	0.45	3.26
17 Approval of technology is often required for small design or part changes			3	4	7	3.57	0.49	3.08
1 Small U.S. market makes it difficult for suppliers to recoup investments in new technology		1	2	4	7	3.43	0.73	2.70
7 Cost of technology approval dissuades developers		1	5	1	7	3.00	0.53	2.47
15 MSHA-specific standards isolate U.S. underground coal mining market		3	1	3	7	3.00	0.93	2.07
21 Conservative and risk averse culture	1		4	2	7	3.00	0.93	2.07
12 MSHA standards are out of date	1	2	1	3	7	2.86	1.12	1.73
24 No federal agency is addressing mining technology needs	1	2	2	2	7	2.71	1.03	1.68
22 Mine operators are resistant change	1	3	3		7	2.29	0.70	1.59
14 Prescriptiveness crowds out novel approaches	1	3	2	1	7	2.43	0.90	1.53
20 The regulatory burden of operating some technologies dissuades operators from using them	1	4	2		7	2.14	0.64	1.50
9 Technology approval applications are canceled when more than minor discrepancies are found	2	1	1	3	7	2.71	1.28	1.44
13 MSHA regulatory environment is unequipped to address new technology	2	1	1	3	7	2.71	1.28	1.44
18 Exceeding minimum safety requirements opens operators to citation for failure of non-required features	2	1	4		7	2.29	0.88	1.41
3 Mine operators lack funds to invest in new technology	2	1	3	1	7	2.43	1.05	1.38
19 Exceeding minimum safety requirements can reveal unknown risks	2	3	2		7	2.00	0.76	1.24
23 Greater liability risk in U.S. compared to other countries acts as disincentive to enter market	2	4	1		7	1.86	0.64	1.22
2 Shrinking market leads to incumbent dominance	3	2	2		7	1.86	0.83	1.02
4 Unwillingness to exceed regulatory requirements for safety technology	3	3	1		7	1.71	0.70	1.01
16 MSHA approval requires revealing proprietary information	4	3			7	1.43	0.49	0.93
5 Technology developers lack resources to commercialize	4	2	1		7	1.57	0.73	0.84
10 Lack of transparency about technology approval application status	4	1	2		7	1.71	0.88	0.83
11 Poor coordination between MSHA & NIOSH	6	1			7	1.14	0.35	0.79
6 Harsh physical environment in mines dissuades potential developers	5		2		7	1.57	0.90	0.67
Average						2.38	0.80	

NOTE: Ratings represent responses to this question: "Please provide your assessment of the relative frequency with which each of the barriers listed below comes into play across the U.S. underground coal mining market overall (4 = most frequent; 3 = more often than most others; 2 = less often than most others; 1 = least frequent)." Table cell values represent the number of responses selecting that rating; cell shading is lightest for the lowest value and darkest for the greatest value. Average and standard deviation are weighted by the number of ratings of a given value.

There was reasonably good consistency between rounds in terms of priorities. Barrier 8 (*duration of technology approval dissuades developers*) was the top priority in both rounds, and four barriers (8, 15, 17, and 1) ranked among the top five in both rounds. After the second round, the top three ranking barriers were 8 (*duration of technology approval dissuades developers*), 17 (*approval of technology is often required for small design or part changes*), and 1 (*small U.S. market makes it difficult for suppliers to recoup investments in new technology*) (Figure 3.2).

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[14] One participant was unavailable for this round, so only seven participants provided ratings. The software we used immediately anonymized participant responses, which precludes us from reanalyzing the first round's results by excluding the responses from the participant who was absent from the second round. The impact of having one fewer participant in the second round is therefore unknown.

Barrier Magnitude

Results for the first and second rounds of ratings of barriers by magnitude are shown in Figures 3.3 and 3.4. The overall degree of consensus again increased between rounds (the average standard deviation decreased 14 percent from 0.84 to 0.72), although again this change was not systematic across individual barriers. Barrier 8 (*duration of technology approval dissuades developers*), was again the top priority in both rounds. Three barriers (8, 17, and 1) ranked among the top four in both rounds. After the second round, the top three ranking barriers were 8 (*duration of technology approval dissuades developers*), 9 (*technology approval applications are canceled when more than minor discrepancies are found*), and 17 (*approval of technology is often required for small design or part changes*) (Figure 3.4).

Figure 3.3. First Round Barrier Magnitude Ratings

	Number of counts by rating							
	1	2	3	4	Σ	Average Rating	Standard Deviation	Avg – SD
8 Duration of technology approval dissuades developers				8	8	4.00	0.00	4.00
17 Approval of technology is often required for small design or part changes			6	2	8	3.25	0.43	2.82
1 Small U.S. market makes it difficult for suppliers to recoup investments in new technology		1	4	3	8	3.25	0.66	2.59
21 Conservative and risk averse culture	1	1	5	1	8	2.75	0.83	1.92
7 Cost of technology approval dissuades developers	1	2	3	2	8	2.75	0.97	1.78
14 Prescriptiveness crowds out novel approaches	1	2	4	1	8	2.63	0.86	1.77
18 Exceeding minimum safety requirements opens operators to citation for failure of non-required features	1	2	4	1	8	2.63	0.86	1.77
15 MSHA-specific standards isolate U.S. underground coal mining market	1	3	1	3	8	2.75	1.09	1.66
13 MSHA regulatory environment is unequipped to address new technology	2	1	3	2	8	2.63	1.11	1.51
12 MSHA standards are out of date	2	2	1	3	8	2.63	1.22	1.41
3 Mine operators lack funds to invest in new technology	2	2	3	1	8	2.38	0.99	1.38
22 Mine operators are resistant change	2	3	2	1	8	2.25	0.97	1.28
4 Unwillingness to exceed regulatory requirements for safety technology	2	5	1		8	1.88	0.60	1.28
9 Technology approval applications are canceled when more than minor discrepancies are found	2	3	1	2	8	2.38	1.11	1.26
23 Greater liability risk in U.S. compared to other countries acts as disincentive to enter market	3	4	1		8	1.75	0.66	1.09
19 Exceeding minimum safety requirements can reveal unknown risks	3	2	2	1	8	2.13	1.05	1.07
20 The regulatory burden of operating some technologies dissuades operators from using them	3	2	2	1	8	2.13	1.05	1.07
2 Shrinking market leads to incumbent dominance	3	2	2	1	8	2.13	1.05	1.07
5 Technology developers lack resources to commercialize	3	4		1	8	1.88	0.93	0.95
24 No federal agency is addressing mining technology needs	4	2	2		8	1.75	0.83	0.92
10 Lack of transparency about technology approval application status	5	3			8	1.38	0.48	0.89
11 Poor coordination between MSHA & NIOSH	7	1			8	1.13	0.33	0.79
16 MSHA approval requires revealing proprietary information	5	1	2		8	1.63	0.86	0.77
6 Harsh physical environment in mines dissuades potential developers	5	1		2	8	1.88	1.27	0.61
Average						2.33	0.84	

NOTE: Ratings represent responses to this question: "Please provide your assessment of the relative magnitude with which each of the barriers listed below comes into play across the U.S. underground coal mining market overall (4 = greatest magnitude; 3 = greater than most others; 2 = less than most others; 1 = least magnitude)." Table cell values represent the number of responses selecting that rating; cell shading is lightest for the lowest value and darkest for the greatest value. Average and standard deviation are weighted by the number of ratings of a given value.

Figure 3.4. Second Round Barrier Magnitude Ratings

	Number of counts by rating							
	1	2	3	4	∑	Average Rating	Standard Deviation	Avg – SD
8 Duration of technology approval dissuades developers				8	8	4.00	0.00	4.00
9 Technology approval applications are canceled when more than minor discrepancies are found		1	4	3	8	3.25	0.66	2.59
17 Approval of technology is often required for small design or part changes		1	4	3	8	3.25	0.66	2.59
1 Small U.S. market makes it difficult for suppliers to recoup investments in new technology		1	4	3	8	3.25	0.66	2.59
15 MSHA-specific standards isolate U.S. underground coal mining market		2	4	2	8	3.00	0.71	2.29
12 MSHA standards are out of date	1		3	4	8	3.25	0.97	2.28
7 Cost of technology approval dissuades developers		3	3	2	8	2.88	0.78	2.09
21 Conservative and risk averse culture	1	1	4	2	8	2.88	0.93	1.95
3 Mine operators lack funds to invest in new technology		4	3	1	8	2.63	0.70	1.93
14 Prescriptiveness crowds out novel approaches	2	1	4	1	8	2.50	1.00	1.50
2 Shrinking market leads to incumbent dominance	2	3	3		8	2.13	0.78	1.34
4 Unwillingness to exceed regulatory requirements for safety technology	2	6			8	1.75	0.43	1.32
13 MSHA regulatory environment is unequipped to address new technology	3		2	3	8	2.63	1.32	1.31
22 Mine operators are resistant change	2	4	2		8	2.00	0.71	1.29
18 Exceeding minimum safety requirements opens operators to citation for failure of non-required features	2	4	1	1	8	2.13	0.93	1.20
20 The regulatory burden of operating some technologies dissuades operators from using them	2	4	1	1	8	2.13	0.93	1.20
23 Greater liability risk in U.S. compared to other countries acts as disincentive to enter market	3	5			8	1.63	0.48	1.14
5 Technology developers lack resources to commercialize	3	3	2		8	1.88	0.78	1.09
24 No federal agency is addressing mining technology needs	3	4	1		8	1.75	0.66	1.09
19 Exceeding minimum safety requirements can reveal unknown risks	3	4		1	8	1.88	0.93	0.95
10 Lack of transparency about technology approval application status	6	2			8	1.25	0.43	0.82
11 Poor coordination between MSHA & NIOSH	7	1			8	1.13	0.33	0.79
6 Harsh physical environment in mines dissuades potential developers	5	2	1		8	1.50	0.71	0.79
16 MSHA approval requires revealing proprietary information	6		2		8	1.50	0.87	0.63
Average						2.34	0.72	

NOTE: Ratings represent responses to this question: "Please provide your assessment of the relative magnitude with which each of the barriers listed below comes into play across the U.S. underground coal mining market overall (4 = greatest magnitude; 3 = greater than most others; 2 = less than most others; 1 = least magnitude)." Table cell values represent the number of responses selecting that rating; cell shading is lightest for the lowest value and darkest for the greatest value. Average and standard deviation are weighted by the number of ratings of a given value.

Final Barrier Prioritization

To complete a final prioritization of barriers, we used a ranking system that combines the frequency and magnitude ratings. For each barrier, we summed the second-round average rating for frequency with the second-round average rating for magnitude to create a combined rating. We similarly summed the second-round standard deviation for frequency with the second-round standard deviation for magnitude to create a combined standard deviation. Then, just as with the individual frequency and magnitude ratings, we ranked the barriers according to the difference between the combined rating and the combined standard deviation. The top eight barriers that emerged from this process are shown in Table 3.4.

Table 3.4. Barrier Rankings According to Combined Frequency and Magnitude Ratings

Combined Average Rating	Combined Standard Deviation	Average – Standard Deviation	Barrier Rank	Barrier	Interview Citation Ranking
7.71	0.45	7.26	1	8. Duration of technology approval dissuades developers	1
6.82	1.16	5.67	2	17. Approval of technology is often required for small design or part changes	8
6.68	1.39	5.29	3	1. Small U.S. market makes it difficult for suppliers to recoup investments in new technology	2
5.88	1.32	4.56	4	7. Cost of technology approval dissuades developers	5
6.00	1.63	4.37	5	15. MSHA-specific standards isolate U.S. underground coal mining market	4
5.96	1.94	4.03	6	9. Technology approval applications are canceled when more than minor discrepancies are found	14
5.88	1.85	4.02	7	21. Conservative and risk-averse culture	10
6.11	2.09	4.01	8	12. MSHA standards are out-of-date	7

All but one of the barriers in Table 3.4 rank in the top eight for both frequency and magnitude individually (barrier 9 [*technology approval applications are canceled when more than minor discrepancies are found*] ranked 12th in frequency and second in magnitude). The general association between frequency and magnitude rankings may indicate that the distinction between the two metrics was difficult for participants to conceptualize and that ratings for both were a somewhat more holistic estimate of overall severity.

The barriers in Table 3.4 also rank highly in terms of the number of stakeholder interviews in which they were cited (taken from Table 3.3), with all but one ranking in the top ten. The fact that these barriers generally rank highly by both frequency of citation in interviews and prioritization ranking in the workshop lends support to their high priority.

In terms of our barrier taxonomy (Table 3.3), all but one of these high-priority barriers fall in the regulatory group. Although the regulatory group includes the majority of barriers (15 of the 24 barriers), the even greater concentration of regulatory barriers among the top eight indicates a relatively higher priority for regulatory barriers compared with other types of barriers.

Although the ranking presented in Table 3.4 accounts for the frequency of occurrence and magnitude of barriers, other factors that may influence priority—such as which stakeholder groups are affected or the opportunities for effecting change—were not considered. Accounting for these and other possible prioritization factors could change barrier rankings.

Session 3: Solutions

The third and final session of the workshop focused on identifying opportunities to eliminate, reduce, or work around barriers. This was an open discussion with no predefined options or methods; participants were free to propose and describe ideas as they liked. Much of the discussion centered on regulatory barriers, presumably both because these are the highest priority and because they are more practically addressable than economic or other barriers. We have organized the participants' recommendations into bullets and subbullets:

- Streamline the MSHA approval process.
  - Revise MSHA's conformity assessment and approval policy to align with that of regulatory agencies around the world that adhere to the IECEx and Appareils destinés à être utilisés en atmosphères explosibles (ATEX) systems:[15] Allow certified outside organizations to assess conformity with standards so that suppliers are not dependent on MSHA approvals.
  - Provide financial and technical assistance to suppliers in obtaining MSHA approval.
  - Allow applicants to pay extra for a rush approval.[16]
- Modernize MSHA standards.
  - Allow the use of more-voluntary consensus standards and harmonize standards among countries.
    - The current proposed regulation to adopt IEC standards (MSHA, 2020a, discussed above under barrier 15 [*MSHA-specific standards isolate U.S. underground coal mining market*]) is an excellent start but excludes important conditions. For example, it does little for higher-powered mining machinery.
  - Revise MSHA standards to bring them up-to-date with current technology and practices.
  - Revise MSHA standards to make them less prescriptive and more performance based.
  - Encourage MSHA to engage in more outside interaction during standards development.
- Create a stakeholder group to have direct involvement with MSHA and NIOSH to help understand new technology needs and facilitate receptiveness to new technology.
- Increase federal support for mining technology.
  - Address more than just safety and health.
  - Expand beyond research and development to include commercialization.
  - Support an information clearinghouse for industry to share problems and solutions.
  - Bring back the Bureau of Mines.

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[15] See Appendix C for more on these systems.

[16] MSHA representatives noted that, as a government agency, MSHA cannot grant special services to applicants with more resources.

Much of the discussion centered on the MSHA approval process and MSHA standards, though other topics were covered as well. Because of time constraints, the session did not include discussion of principal actors, which barriers a recommendation addresses, or the feasibility of implementing a recommendation. Some of this information is readily inferable, however. For example, the recommendations directly address several barriers, including six of the top-priority barriers from Table 3.4:

- 7. Cost of technology approval dissuades developers.
- 8. Duration of technology approval dissuades developers.
- 9. Technology approval applications are canceled when more than minor discrepancies are found.
- 12. MSHA standards are out-of-date.
- 13. MSHA regulatory environment is unequipped to address new technology.
- 14. Prescriptiveness crowds out novel approaches.
- 15. MSHA-specific standards isolate U.S. underground coal mining market.
- 17. Approval of technology is often required for small design or part changes.
- 5. Technology developers lack resources to commercialize.
- 24. No federal agency is addressing mining technology needs.

Similarly, principal actors for several barriers are reasonably clear. Recommendations addressing regulatory changes are generally within the purview of MSHA, although the extent to which certain changes might require legislative involvement is unclear. The actors for the nonregulatory recommendations are less clear and may be suited to addressing through interagency coordination.

Although feasibility was not discussed explicitly, several participants suggested that facilitating changes may benefit from interagency coordination. The general sense was that it is very difficult to change the status quo and that MSHA operates and evolves largely independently.

Chapter 4

Conclusion

Our analysis identified and characterized 24 distinct barriers to the development, commercialization, and adoption of new technology in the underground coal mining market. The majority of barriers are related to regulatory issues (62 percent), followed by economic issues (25 percent) and other issues (13 percent). Regulatory barriers are associated with the approval of technologies for use in permissible environments in underground coal mines and cover the cost and duration of approval, the currency and prescriptiveness of the regulations, the burden on mine operators, and the regulatory culture. Economic barriers are related to insufficient supply and demand and the specialized market of underground coal mining. Other barriers are a mining culture that is resistant to change, liability risks, and a lack of federal support.

The type of barrier has implications for the prospects of and options for eliminating it, as well as the roles of different actors in implementing those options. In general, economic barriers may be the most challenging to address, as they are inherently linked to the global energy economy and energy policy. Addressing them would involve national policy decisions and the coordination of a large number of different stakeholders. Addressing the regulatory barriers, on the other hand, would involve more-localized efforts and fewer stakeholders. In particular, addressing regulatory barriers would necessarily require substantial involvement by MSHA.

The most commonly cited barrier was cited in 29 of the 75 interviews, while two barriers were cited just once each (Table 3.3). The eight highest-priority barriers, as determined by stakeholder perceptions of frequency of occurrence and magnitude, consist of seven regulatory barriers and one economic barrier (Table 3.4). The highest-priority barriers and proposed solutions focus primarily on modernizing and harmonizing MSHA's standards and approval process with best practices used in other countries.

The findings have some useful implications for NIOSH. For example, given that mine operators are reluctant to exceed regulatory requirements for safety technology, NIOSH may want to consider potential regulatory requirements when investing in new technology research. Considering technologies that are most likely to help mine operators meet regulatory requirements rather than pursuing technologies unrelated to meeting regulatory requirements may achieve more success. Still, even in the case of a new technology (especially if it is particularly novel) that could in principle help mine operators meet regulatory requirements, technology suppliers may face challenges in obtaining MSHA approval or may decide that it is not worth the effort and risk to even make the attempt. In terms of ways in which NIOSH may facilitate the elimination of barriers, NIOSH research on the equivalency between MSHA and IEC standards has already proven essential to MSHA's willingness to consider granting technology approval according to IEC standards in lieu of MSHA standards (Calder, Snyder, and Burr, 2018). The majority of barriers, however, relate to issues that are beyond NIOSH's direct influence, and NIOSH is likely to play a secondary role in addressing them.

Appendix A

Interview Protocols

Main Interview Protocol

Note: Questions 1 and 2 were for mine operators only. Questions 3 and 4 were for technology suppliers and researchers only.

1. How do you learn about new technologies?
2. What factors influence your organization's decisions to use or not use particular technologies? Please rank each factor in terms of its relative importance (multiple factors can have the same ranking).
    a. Regulatory requirements
    b. Impacts on worker safety and health
    c. Worker acceptance
    d. Effects on productivity
    e. Cost—upfront investment or operations & maintenance (including reliability)
    f. Other
3. Please walk us through the technology development, approval, and commercialization process.
4. When considering recent technologies you've developed for underground coal mining,
    a. How is technology development financially supported?
        i. Internal funds
        ii. Partnerships with operators
        iii. Outside investors
    b. What are the worker safety and health-related implications of the new technology relative to existing technologies?
    c. What are the productivity or profitability implications of the new technology relative to existing technologies?
    d. Is the technology intended for environments beyond underground coal mining? Beyond mining? If yes, which environments?
5. In what environments are new technologies tested & demonstrated?
    a. Laboratories
    b. Test mines (non-producing)
    c. Non-production areas of working mines
    d. Working mines
    e. Other

6. What are the main considerations and barriers involved in introducing new technologies?
    a. Are there distinct barriers for technology development, commercialization, and adoption?
7. Do you have any observations or recommendations about ways to reduce these barriers?
8. What technologies available in other countries or other industries (e.g., explosion-proofing methods) would you like to see available for underground coal mining in the U.S.?
    a. What prevents them from being available for U.S. underground coal mining?
    b. What are the worker safety and productivity implications of them not being available?
9. Are you aware of new technologies that were proposed or developed but were never investigated further or commercialized?
    a. Why are some ideas pursued and others not?
    b. What are the worker safety and productivity implications of them not becoming available?
10. Are you aware of any technologies not having a similar alternative that have been discontinued?
    a. Why are some technologies retained and others discontinued?
    b. What are the worker safety and productivity implications of them not being available?
11. How is technology development and adoption affected by the industry economic upswings and downswings?

Protocol for Regulators

Technology Approval Process

1. Please walk us through the technology approval process.
2. How do approval criteria for experimental permit, field modification, 101(c) petition, and full approval differ from each other?
3. How do re-applications and applications for modification differ from new applications?
4. What happens when an application involves technology for which no clear standard applies or for which the evidence base is lacking?
5. How does your agency consider experience and data from manufacturers, NIOSH, or others in its evaluations?

Approval Based on Non-MSHA Standards

6. What is your understanding of MSHA processes of verifying and accepting non-MSHA standards?
7. Why did MSHA begin allowing approval evaluation according to non-MSHA standards?
8. How does a non-MSHA standard get considered for equivalency?
9. About what fraction of applications seek approval based on the IEC flameproof enclosures standard?

10. Are there plans to increase reliance on IEC and other voluntary consensus standards?

Policy and Rule Development

11. How does MSHA develop new standards?
12. What is the motivation?
13. Who reviews and makes decisions about comments submitted in response to EO 13777 on regulatory reform?
14. What research are MSHA standards based on?
15. Are there MSHA-specific rules or policy on collaboration in the rulemaking process?
16. Are there rules or policy on transparency about the status of an application?
17. Why did MSHA eliminate discrepancy letters? What have the implications been?
18. What is the pricing structure for applications?

Overall Impressions

19. When considering MSHA's technology approval system overall,
    a. What aspects work well?
    b. Which aspects need improvement?
    c. What would you change?

Appendix B

Workshop Agenda

Workshop on Barriers to the Development, Commercialization, and Adoption of Underground Coal Mining Technologies

Date: Tuesday, October 12, 2021
Time: 12:00pm–5:00pm eastern/11:00am–4:00pm central/9:00am–2:00pm pacific
Location: Virtual

Agenda

Time (eastern)	Topic
12:00–12:10	Welcome and introduction
12:10–12:45	RAND Interviews
12:45–1:45	Session 1: Refine Barrier Taxonomy
1:45–2:00	Break
2:00–3:30	Session 2: Prioritize Barriers
3:30–3:45	Break
3:45–4:45	Session 3: Solutions
4:45–5:00	Wrap-up

Appendix C

Comparison of Testing, Evaluation, and Approval Regimes for Electric Equipment in Underground Coal Mines Among Different Countries

This appendix presents a brief comparison of the regulatory regimes for the approval of electrically powered equipment for use in gassy mine environments in different countries. The comparison is based on our review of government regulations, independent standards development organization documents, and academic and grey literature discussing differences in regulatory regimes. We also conducted two additional interviews with industry representatives with specific expertise in certifying underground coal mining equipment in multiple countries. This analysis is restricted to equipment approval and does not consider other aspects of mine safety and health regulations.

The term *gassy mine* includes multiple mined commodities, although the vast majority of such mines are underground coal mines. Gassy mines contain ignitable levels of combustible gasses or dust, and hence there is a risk of heat or sparks from electrically powered equipment causing a fire or explosion, which would constitute a grave safety risk to workers. Most electrically powered equipment used in gassy mines and other flammable or explosive environments must therefore be specially designed according to regulations intended to minimize this risk. In general, mine equipment must be designed in such a way as to either not produce a spark or heat sufficient to ignite a combustible atmosphere or be contained within an enclosure that can withstand an internal explosion without igniting the surrounding combustible atmosphere (MSHA, 2020a). In the United States, equipment meeting requirements by following the first approach is known as *intrinsically safe*, while equipment following the second approach is known as *explosion proof*. Mining machinery and components approved for use in gassy mines by MSHA will be noted as *MSHA approved* and are known as *permissible* and may employ one or both approaches.

At a general level, safety regulation systems consist of safety *standards* and a process by which equipment is certified to meet a standard, known as *conformity assessment* (IECEx, 2018). Standards, the types of organizations that develop standards, and the organizations and processes used for conformity assessment can vary considerably by industry and by country. Below, we discuss the differences in standards and conformity assessment among some of the major underground coal producing countries.

Standards for Fire and Explosion Protection Used in Underground Coal Mining Environments

Standards provide specifications for the design, construction, performance, and testing of equipment. With regard to equipment for use in flammable atmospheres, including underground coal mining environments, standards address such topics as materials, joints and fasteners, cables and connectors, batteries, motors, electrical circuit requirements, criteria for intrinsic safety, and inspection and testing requirements. Standards can be developed by government agencies or independent standards development organizations. Government standards are typically developed by regulating agencies and are included in the regulations themselves. Standards developed by standards development organizations are known as *voluntary consensus standards* (VCSs) but become mandatory when they are incorporated into government regulations by reference.

United States

Standards for Mining

In the United States, standards for equipment used in flammable atmospheres in underground coal or other gassy mining environments are developed and promulgated by MSHA within the U.S. Department of Labor. The development of these standards goes back to the early 20th century. Current standards are promulgated by MSHA in response to legislation such as the Federal Coal Mine Health and Safety Act of 1969 (Coal Act), the Federal Mine Safety and Health Amendments Act of 1977 (Mine Safety and Health Act), and the Mine Improvement and New Emergency Response Act of 2006 (MINER Act). These standards are described in Chapter I (Mine Safety and Health Administration, Department of Labor) of Title 30 (Mineral Resources) of the Code of Federal Regulations.

The U.S. regulatory regime for mining in hazardous environments differs from that of most other countries in that the relevant standards in the United States are written specifically for a mining environment. Most other countries (and other industries in the United States) use standards that apply more broadly to all types of work environments with flammable atmospheres. As a result, in addition to addressing individual materials and components, MSHA standards address design, construction, and performance requirements of mining-specific equipment, such as headlamps, methane detectors, and dust samplers, as well as assembled mining machines, such as longwall mining systems and continuous mining machines.

It is common practice for standards to incorporate by reference other standards when the existing standards are deemed appropriate. Many parts of MSHA's regulations (in the Code of Federal Regulations) incorporate external standards from the several standards development organizations, including

- National Fire Protection Association (Parts 56, 57, 75)
- ASTM International (Parts 7, 47, 56, 57, 75, 77)
- ANSI (Parts 56, 57, 72)
- Underwriters Laboratories (Parts 28, 75)

- American Welding Society (Parts 7, 77)
- Institute of Makers of Explosives (Parts 56, 57, 77)
- American Conference of Governmental Industrial Hygienists (Parts 47, 56, 57, 71, 75)
- National Board of Boiler and Pressure Vessel Inspectors (Parts 56, 57)
- Society of Automotive Engineers (Parts 56, 57, 77)
- American Society of Mechanical Engineers (Parts 56, 57, 75, 77)
- International Association of Plumbing and Mechanical Officials (Parts 71, 75)
- Institute of Electrical and Electronics Engineers, Inc. (Parts 74, 75)
- IEC (Parts 6, 7, 18, 74)
- International Organization for Standardization (Parts 74)
- regulations from several other U.S. federal government agencies.

These incorporated standards cover a wide variety of issues, but none is associated with safety for equipment for use in flammable atmospheres (except the IEC standards, which are heavily modified by MSHA, as noted below). All standards used by MSHA for such requirements have been developed internally by MSHA or its predecessors (U.S. Bureau of Mines, Mining Enforcement and Safety Agency). Part 6 of MSHA's regulations (Code of Federal Regulations, Title 30, Part 6) does allow for the use of non-MSHA standards for equipment for use in flammable atmospheres but only after MSHA has made a determination that the external standard is at least as safe as the MSHA standard or can be modified so that it is as safe as the MSHA standard. Modified versions of two such standards from the IEC have been incorporated by reference into the MSHA regulations (60079-0 and 60079-1) (Code of Federal Regulations, Title 30, Section 7.10). However, multiple stakeholder interview participants noted that the modifications are so extensive that equipment suppliers have ignored them and continue to use the MSHA standard.

Standards Development

A corollary of the United States standing largely alone in the world in having safety standards for equipment used in gassy mines custom designed by a government regulatory agency that focuses specifically on mining is that MSHA standards are developed in relative isolation from the national and international standards development communities. Interview participants noted that MSHA "does not collaborate in rulemaking; it's not like the process for VCSs."

One consequence of the approach used by MSHA is that MSHA does not necessarily follow best practices for standards development as identified by other industries or countries (e.g., ANSI's essential requirements; see ANSI, 2022). For example, MSHA standards are often characterized by industry representatives as being overly prescriptive, which is inconsistent with most standards development organizations' and regulatory bodies' preference that standards be based on performance criteria rather than design criteria, when appropriate (U.S. Office of Management and Budget, 2016).

Another consequence of this isolation is that MSHA is solely responsible for the stewardship and updating of its standards. The majority of MSHA standards were developed for regulations in response to the 1969 Coal Act and 1977 Mine Safety and Health Act. Industry representatives have noted that many of these standards are out-of-date. This position is supported by the fact that several of the external standards incorporated by reference are versions dating from the 1960s and 1970s (see examples, above). Although MSHA has the ability to revise its regulations to update standards, many standards remain unchanged from the original version.

Countries Other Than the United States and Other Industries in the United States

Standards

Nearly all other major coal-producing countries use IEC standards as a starting point for requirements for equipment used in hazardous environments in underground coal mines. The IEC is an international independent standards development organization whose mission is "to achieve worldwide use of IEC International Standards and Conformity Assessment Schemes to ensure the safety, efficiency, reliability and interoperability of electrical, electronic and information technologies, to enhance international trade, facilitate broad electricity access and enable a more sustainable world" (IEC, undated-c).

As an independent standards development organization, the IEC has no enforcement authority. Rather, government regulatory agencies may adopt IEC standards by incorporating them by reference into regulations. The IEC allows countries to make modest revisions or augmentations to its standards, known as *national differences* or *national deviations* (IECEx, 2022).

According to the experts with whom we met, many countries have adopted IEC standards with no or only minor deviations, as has the United States for OSHA-regulated industries. We confirmed this by checking a sample of countries' individual versions of five IEC standards related to equipment design and performance in hazardous atmospheres (IEC 60079-0, 60079-1, 60079-7, 60079-11, and 60079-25; see IECEx, undated-b). With the exception of one standard in one country (60079-0 in Australia), standards for Australia, New Zealand, India, South Africa, and Brazil indicate that they are identical to the IEC standards (Standards Australia, 2021; Bureau of Indian Standards, 2012; South African Bureau of Standards, 2021; Borges, undated).

The European Union plus other European countries use the ATEX standard system (European Commission, undated). Although the ATEX system does not specify specific standards and instead recognizes any standard that meets the Essential Health and Safety Requirements of the ATEX Directives (IECEx, 2008), the European Commission provides an approved list of harmonized standards, which includes all the relevant IEC standards (European Commission, 2023).

Experts we spoke with noted that China and Russia use standards that are modified versions of IEC standards. For example, RussianGost standard 60079.1 states, "The requirements established by this standard supplement and modify the general requirements set out in IEC 60079-0" (RussianGost, 2013). Although we were not able to obtain a description of specific national differences, the experts we interviewed for this comparative analysis explained that these differences are generally modest. Hence, although China and Russia do not necessarily follow the IEC standards and conformity testing system as closely as those countries described above, experts noted that the difference between Russia and China and the other non-U.S. countries is nonetheless small compared with the difference between the United States and any other country. Experts also noted that China and Russia regularly update their standards to follow IEC standards.

Standards Development

As part of its effort to be a global source of standards, IEC strives to "reflect the global consensus and distilled wisdom of many thousand technical experts" in its standards development process (IEC, undated-b). In developing standards, IEC uses a multistage process that consists of national committees, technical committees, rules for accepting proposals for new standards, iterations of initial drafts based on committee member comments, and voting on final drafts (IEC, undated-a).

IEC standards are updated regularly (typically every three to 12 years, with the update interval depending on the maturity and rate of evolution of the relevant technology area (IEC Webstore, undated). Specific country versions of those standards are subsequently updated to refer to the most current version of the IEC standard.

Conformity Assessment for Fire and Explosion Protection Standards for Underground Coal Mining Environments

Conformity assessment is the general term for any system of review, inspection, and testing to ensure and certify that equipment meets a particular safety standard. In addition to ensuring that equipment submitted for approval meets a standard, conformity assessment can include the routine inspection and auditing of products, facilities, processes, and staff qualifications of manufacturers, testing laboratories, and service organizations to ensure the ongoing quality and consistency of equipment production, testing, and servicing. This assessment is an essential element of any safety standard system, as it provides the evidence that equipment meets and will continue to meet a standard.

United States

In the United States, MSHA is responsible for conformity assessment of equipment for the mining industry, and OSHA is responsible for conformity assessment for all other industries. The process includes engineering review of drawings and specifications, testing of sample products, and approval and certification of components and assembled machines. MSHA can conduct most of the tests internally, although MSHA regulation allows for testing to be conducted by approved independent testing laboratories (Code of Federal Regulations, Title 30, Part 6, Section 6.10). MSHA allows testing by laboratories that have been recognized through OSHA's Nationally Recognized Testing Laboratory program and the IECEx scheme (MSHA, undated-b). Standards generally include required testing procedures, so independent laboratories conduct the same tests that MSHA would conduct.

To be accredited by the Nationally Recognized Testing Laboratory program or IECEx scheme, independent testing laboratories undergo periodic in-depth reviews that include an on-site assessment to ensure that the laboratory meets the accrediting organization's requirements to provide reliable, high-quality testing services (OSHA, undated-b; IECEx, 2022). No sort of review, assessment, or accreditation is conducted for internal MSHA testing facilities because there is no requirement to do so; reportedly, the inclusion of the MSHA facilities in these approval processes has never been attempted due to cost and other reasons.

MSHA is the official approving and certifying entity. Regardless of whether testing is conducted internally by MSHA or externally by an approved independent testing laboratory, MSHA reviews test results in conjunction with its overall review and approval decision.

In addition to formal approval of new technologies, MSHA provides other types of equipment approvals. When a manufacturer makes a change to an approved product (e.g., to include new parts or designs), it must submit the revised design to MSHA for approval through the Revised Approval Modification Program (RAMP). Under RAMP, "MSHA expedites applications for acceptance of minor changes to previously approved, certified, accepted, or evaluated products" (Code of Federal Regulations, Title 30, Part 5, Section 5.30[e][3]). MSHA also grants three types of approvals to equipment users (as opposed to manufacturers)—typically, mine operators. MSHA may grant an approval for a field modification of a piece of approved equipment (Code of Federal Regulations, Title 30, Part 18, Section 18.81), grant a permit to use an experimental piece of equipment (Code of Federal Regulations, Title 30, Part 18, Section 18.82), or allow a piece of equipment to be used by granting a petition for modification of a mandatory safety standard (Code of Federal Regulations, Title 30, Part 44).

Although MSHA regulations allow for postapproval product audits (Code of Federal Regulations, Title 30, Part 7, Section 7.8), these audits focus only on the product itself; MSHA does not conduct any type of inspection or audit of suppliers' facilities or procedures.

Countries Other Than the United States

The IEC has developed a suite of standard conformity assessment schemes, one of which is IECEx. IECEx consists of IEC standards plus performance criteria and certification systems for testing laboratories, certification bodies, service facilities, personnel competencies, and other elements (IECEx, 2018, 2022b). Testing labs, certification bodies, and other elements of the IECEx scheme are equipped to accommodate national deviations, so the IECEx scheme is applicable to all countries that accept IEC standards.

An *accepted* IECEx certification body is any entity approved by IECEx to endorse test results and to provide a certificate of conformity to a piece of equipment. Examples include UL Standards & Engagement, Intertek, and FM Approvals in the United States (the United States follows IECEx for industries other than mining) and TestSafe (operated by the New South Wales government) and Simtars (operated by the Queensland government) in Australia (IECEx, undated-a). A certification body may have its own testing facilities, or it may contract out to an accepted independent testing laboratory.

The IECEx scheme also includes a process by which certification bodies conduct periodic assessments of manufacturing facilities to ensure that they meet all the requirements of the relevant standards. Results of these assessments are recorded in quality assessment reports.

Lastly, the IECEx scheme includes a process for the certification of installation, inspection, maintenance, and repair service providers, which includes dedicated standards for these services, as well as for the competency of persons using and servicing the approved equipment (IECEx, 2018, 2022b).

Most countries that use the IECEx system follow this scheme closely, although there are variations. For example, Queensland, Australia, recognizes only certificates of conformity issued by an IECEx certification body located in Australia. And, as noted above, although China and Russia have adopted standards that are similar to the IEC standards, they do not participate in the IECEx conformity assessment system. These countries conduct testing and conformity assessment using independent systems.

Machine Approvals

Beyond conformity assessment and certification of individual components (e.g., electric motors), most countries also require approval of assembled machines before they are approved for use (machine approvals). Machine approval requirements differ significantly from country to country and also depend on the equipment type. Considerations for machine approvals include but are not limited to confirmation that all the explosion-proof components are certified and marked correctly, brake testing, noise testing, review of ergonomics for the operator, load locks to ensure that cylinders do not lower or raise on loss of power, testing of canopies and falling-object protection, review for fire resistance and antistatic, electrical protection for touch potential, and electromagnetic compatibility testing.

In most cases, machine approvals are directly conducted by government-certified companies (separate from component certification bodies) or government agencies (e.g., in the United States and India). Exceptions to this are Australia, the European Union, and the United Kingdom. Australia places responsibility and liability to ensure that the assembled machine meets safety and regulatory requirements on the end user. Consequently, the machine approval role is effectively assumed by customers, who generally demand very detailed safety and regulatory files and compliance documentation. The European Union and United Kingdom, which use the ATEX system, require suppliers to issue a declaration of conformity for the whole machine; so while the ATEX system mirrors the IECEx standards and conformity assessment process for components, it adds a machine-level conformity declaration.

Summary

The following are some observations taken from this comparative analysis that may be useful to NIOSH and MSHA in their efforts to modernize the underground coal mining technology approval regulatory regime in the United States:

- The United States is the only country we are aware of in which a single organization performs regulatory oversight and enforcement, standards development, and conformity assessment. Further, this single organization's jurisdiction is restricted to only mining. This leaves the U.S. mining industry at risk of operating in isolation of technological input and progress from other industries and other countries.

- In the United States, standards for mining equipment used in hazardous environments are developed by MSHA and are unique to the U.S. mining industry. All countries other than the United States and all industries other than mining use standards identical to or very similar to the IEC standards.
- Certification that electrical components conform to required standards is conducted by MSHA for mining equipment in the United States and by approved independent certification bodies in other countries and for industries other than mining in the United States.
- Most countries require mining machines assembled from certified components to receive a machine approval from a government-certified company. In European countries, suppliers are responsible for issuing machine approvals. In Australia, machine approvals are effectively handled by customers.
- Although equipment approval requirements differ among countries, the differences among non-U.S. countries are small compared with the difference between the United States and non-U.S. countries. An important implication of this difference is that design requirements for the U.S. market are so specialized that manufacturers must typically design, produce, and market a separate product for the U.S. market. One expert interviewed for this analysis opined, "There is no feasible way for a product designed to meet a non-U.S. country's requirements to also meet the MSHA requirements."

Abbreviations

ANSI	American National Standards Institute
ATEX	Appareils destinés à être utilisés en atmosphères explosibles
EIA	U.S. Energy Information Administration
EO	executive order
IEC	International Electrotechnical Commission
IECEx	International Electrotechnical Commission System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres
MINER Act	Mine Improvement and New Emergency Response Act of 2006
MSHA	Mine Safety and Health Administration
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
VCS	voluntary consensus standard

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